ELEMENTS

OF

APPLIED ELECTRICITY

BY

H. H. BLISS

State Supervisor of Trade and Industrial Education for Nevada.
Formerly in charge of Extension Engineering Courses
for the University of California

PUBLISHED BY
JOURNAL OF ELECTRICITY
SAN FRANCISCO, CALIFORNIA

1920

ELEMENTS

OF

APPLIED ELECTRICITY

BY

H. H. BLISS

State Supervisor of Trade and Industrial Education for Nevada.
Formerly in charge of Extension Engineering Courses
for the University of California

FIRST EDITION

PUBLISHED BY

JOURNAL OF ELECTRICITY

SAN FRANCISCO, CALIFORNIA

1920

PREFACE

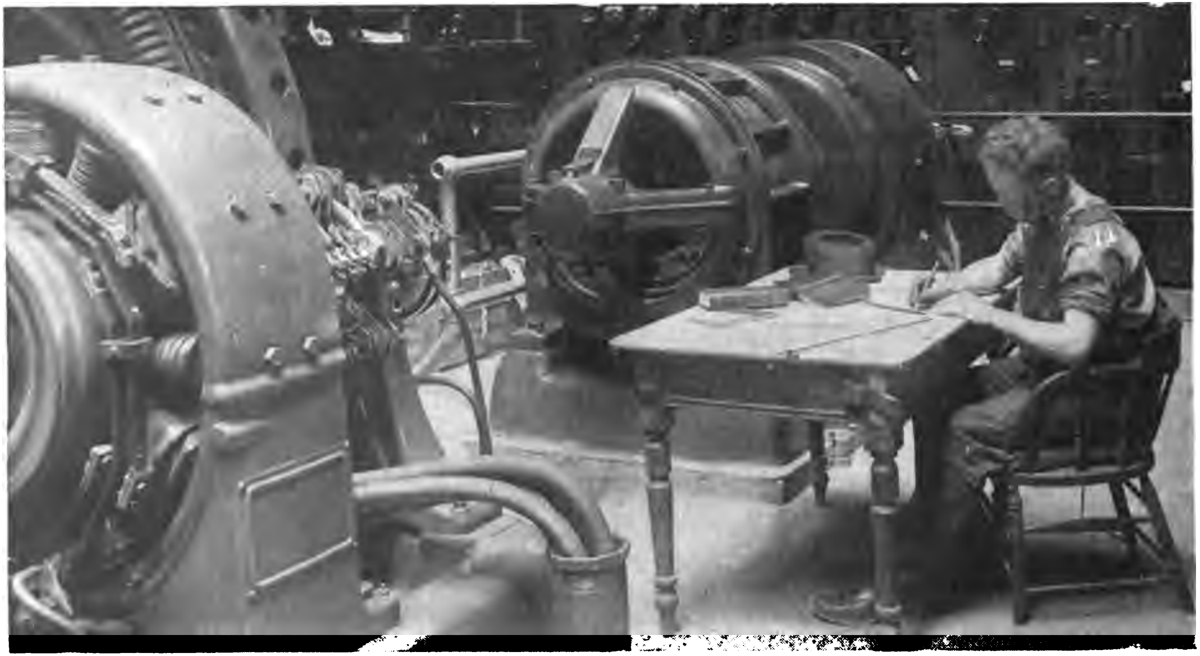
What do you know about electricity? Can you explain simple circuits, losses, power and efficiency, wiring calculations, how generators and motors are installed, how they work, what efficiency means and how to calculate it, and how current for electric lighting and heating is estimated?

"Know the fundamentals" is the cry of the hour. Here is a series of discussion which has appeared in the columns of the Journal of Electricity in cooperation with the Extension Division of the University of California on the all-important subject of elementary laws of electricity. The forwarding of this movement is a matter that strongly appeals to every member of the electrical industry — manufacturers, jobbers, central station men, electrical contractors and dealers—and has received the heartiest endorsement of the electrical industry from all quarters. These discussions which appeared in the columns of the Journal of Electricity during the year of 1919-1920 under the endorsement of the California Electrical Cooperative Campaign, an organization composed of all members of the electrical industry, have received wide and emphatic endorsement.

The author, Mr. H. H. Bliss, for a number of years was head of the technical instruction of the Extension Division of the University of California, and while occupying that position gave this course through the University Extension in cooperation with the Journal of Electricity. The course proved unusually successful, and aroused interest throughout the West in the study of fundamentals. It is with this same hope that this group of papers may prove of increasing helpfulness that the Journal of Electricity has compiled these pages into book form in order that a permanent record may be had with these papers in one volume so that the biggest and most intensified use of this valuable collection may be offered to that ever growing group of young and enthusiastic as well as ambitious men in our industry who wish to forward themselves to greater remuneration from their employers and to greater usefulness in their chosen profession.

ROBERT SIBLEY, Editor,
Journal of Electricity.

TABLE OF CONTENTS



Electrical computation in the power plant. The best investment of spare time is in study leading to self-improvement and to advancement in one's vocation. Electrical workers enjoy exceptional opportunities of this kind.

ELEMENTS OF APPLIED ELECTRICITY

I

OHM'S LAW AND THE ELECTRIC CIRCUIT

Our discussion of electrical principles and practice begins with the consideration of Ohm's Law, which is the basis of all quantitative knowledge of circuits and machines. Its fundamental character is recognized in the industry, and the National Electric Light Association has adopted for its official emblem the Ohm's Law formula "$C = E/R$," which appears upon all the stationery and official documents of this nation-wide organization.

Electric Currents.—In order to utilize electric energy it is necessary to connect the source of the current, such as a battery or generator, to other apparatus, such as motors, heaters, or lamps. There must be a continuous path for the current from the source to the point of use and back again to the source. As soon as this circuit is broken at any point the current stops.

The materials which can carry electricity are called "conductors." They include all metals, both when solid and liquified (as mercury or melted iron); carbon; impure water; earth; moist woods, etc. Materials which stop the flow of electricity more or less completely are termed "insulators." These in-

dude glass, porcelain, marble, slate, rubber, paper, cloth, wax, dry wood, etc. The fact that any water, except chemically pure distilled water, can carry electricity causes such materials as wood, cloth, paper, dirt, etc., to fall into one class or the other according to whether they are dry or wet. And

A current of gas may be measured in cubic feet per minute, by means of this meter and a watch; an electric current is more easily measured, in "coulombs per second" or "amperes," by means of a single instrument, the ammeter. The current in either case must go through the meter. (See Fig. 1.)

small particles or veins of metal in insulating materials sometimes lead the current to places where it is a source of annoyance or danger. Air is generally an insulator, but under certain circumstances it becomes a conductor, as, for example, in the electric arc where large currents flow for a short distance through air.

Measuring Electric Current. — A current of water in a pipe or a river can be metered in various ways, and the rate of flow can be stated in terms of gallons per second. In a similar way the rate of flow of an electric current can be stated as so many "coulombs per second," but it is more customary to substitute for this phrase the single word "amperes." A statement that "the current is 16 amperes" means that 16 coulombs pass a given point in the wire every second.

Tungsten lamps take currents ranging from .23 to .91 amperes in the sizes commonly used (25 to 100 watts); arc lamps take from 3 to 20 amperes; a 10 horsepower motor on a 250 volt circuit will take about 40 amperes.

To measure the rate of flow in an electric circuit we use an instrument called an "ampere meter" or "ammeter." It is inserted into the circuit, as shown in Fig. 1, so that the current must go **through** the instrument between the source and the load. A needle shaped pointer moving over a scale gives a reading of the current in amperes.

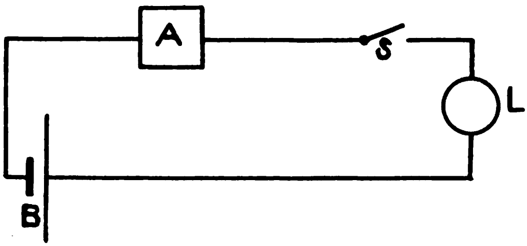


Fig. 1.—The current goes through the ammeter between the battery and the lamp. When the switch (S) is opened the battery (B) can no longer send current to the lamp and the ammeter needle points to the zero mark.

Resistance.—If in the circuit of Fig. 1 we replace the lamp by one of different candle power or by a piece of fine iron wire or by an electric bell, we shall find the ammeter giving an entirely different reading. The battery tries equally hard to force electricity through the circuit, but the amount it can send depends upon the apparatus through which the current must flow. We may say that the lamps differ in the amount of "**resistance**" they offer to the passage of electricity. If one takes three times as many amperes as a second, we may say that it has one-third the resistance of the second.

Electrical resistance is measured in "ohms." It is thought of as a sort of "electrical friction," like the opposition a rough pipe offers to the flow of water through it. The resistance of a 25 watt Tungsten lamp is about 485 ohms; that of an electric

iron, about 25 ohms; the resistance of a piece of copper wire 1/10 inch in diameter and 1000 feet long is one ohm.

When this switch is opened it stops the current in a high tension power line by interposing an air resistance of millions of ohms. When closed, the resistance of the switch is practically zero. The current carried may amount to 300 amperes. To prevent the escape of current, under the enormous pressure of 110,000 volts, the switch has to be supported upon these huge insulators. Switches of this type are to be used in connection with the Chicago, Milwaukee & Puget Sound—the first electric transcontinental railway.

Pressure.—We come now to the consideration of a third factor in electric circuits, namely, the **"pressure"** which forces the current through the wires. There is evidently something in a battery or an electric generator which forces electricity to go out at one terminal and to come back at the other, just as a pump sends water out at one place and draws it in at another. Of course, an open switch or a closed valve may block the flow, but the electric pressure or water pressure is still ready to start the current when opportunity is offered.

Water pressure is measured in pounds per square inch, by means of a pressure gage. The unit of electrical pressure is the "volt." The pressure or "voltage" in ordinary house circuits is about 110 volts; a dry battery has a pressure of about 1.5 volts; the voltage applied to street car motors is usually about 550.

There should be no confusion about the words **ampere and volt.** The number of **amperes** indicates the **rate of flow,** without reference to the pressure driving the current. Then "110 volts" indicates only a tendency to send current with no reference to how much, if any, actually flows. We may have 110 volts and 1, 5, or 500 amperes, or no flow at all, depending upon the resistance in the circuit.

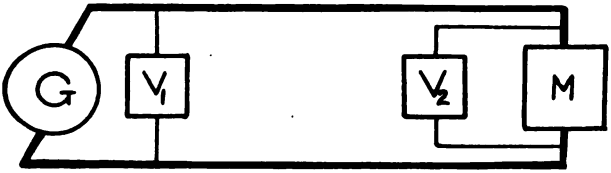


Fig. 2.—Voltmeter V_1 measures the electromotive force of the generator; V_2 measures the pressure applied to the motor.

To measure pressure we use a "**voltmeter,**" an instrument which somewhat resembles an ammeter. To find what voltage is sending (or available to send) current through a circuit or piece of apparatus, we connect one terminal of the voltmeter to each end of the circuit or to each terminal of the appa-

Here is an electric warming pad—quite a companion on cold nights. Attached to a 110 volt circuit it takes a current of one-half an ampere. What is its resistance?

ratus. In Fig. 2 the voltmeter marked "V_2" measures the "voltage across the motor" (the pressure tending to send current through the motor), while the other voltmeter measures the pressure the gen-

erator exerts to send current through the whole circuit. The two instruments need not give equal readings.

Ohm's Law.—One volt is the pressure needed to send one ampere through one ohm resistance. From this it follows that the number of volts required to send a current through any resistance is equal to the product of the numbers of amperes and ohms. This statement, which is known as Ohm's Law, may

Here is a typical example of the use of insulators and conductors in long distance transmission of electric power. The famous crossing of the lines of the Pacific Gas & Electric Company, at Carquinez Straits in California was for years the most daring enterprise of its kind and today it ranks as the second longest span in the world. Each of the six cables consists of 19 strands of steel wire, making a composite size for each cable of 7/8-inch diameter, with the remarkable length of 6200 ft. Assuming that a cable 6200 ft. long, equivalent to No. 1 copper wire, has a resistance of 0.77 ohms and a carrying capacity of 150 amperes, what is the voltage required to force the current through this resistance, according to Ohm's Law?

be indicated by a brief formula: "Volts = amperes × ohms." Other ways of writing it are: "Amperes = volts ÷ ohms" and "Ohms = volts ÷ amperes." All three formulas should be memorized.

The second of the three formulas may be written: "Current = electromotive force ÷ resistance." Using initials instead of words, $C = E \div R$. This is

the symbolic representation of the law as used in the emblem of the N. E. L. A. shown at the head of the chapter.

II

SERIES AND MULTIPLE CIRCUITS

Series Circuits.—Many electric circuits consist of several different parts through which the current passes in "**series.**" This means that the electricity must go through one part after another. Make a clear distinction between this arrangement and the "**multiple**" circuit in which the current divides and flows through several branches. Fig. 3 illustrates the first and Fig. 4 the second type.

What is said about these applies to direct current circuits and also to those alternating current

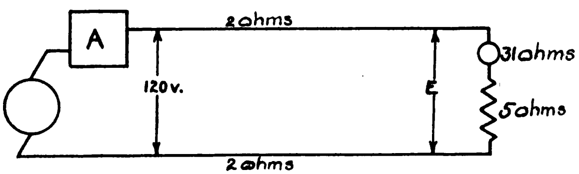


Fig. 3.—Resistances in Series. In spite of the varying resistance of the various elements of the circuit, the current passing through each is the same—3 amperes.

circuits which contain only simple resistance and no electromagnetic apparatus or condensers.

The current leaving the generator in Fig. 3 goes first through an ammeter, then through the upper wire, then through a lamp, then through a resistance coil, and finally back to the generator through the lower wire. It is obvious that if 3 coulombs per second (3 amperes) pass through the generator to the ammeter, the same number must travel along the upper wire through the lamp and the coil and

back to the generator through the lower wire. If any more coulombs passed out through the ammeter than came back through the lower wire there would be an accumulation of electricity somewhere in the right hand part of the circuit; if any more returned to the generator than left it there would be a production of coulombs somewhere in the right hand part of the circuit. Both of these alternatives are impossible with this apparatus and hence we conclude that:

In a series circuit **the current is the same everywhere.**

If a resistance of 2 ohms is in a series of another of 3 ohms, the electromotive force must overcome 5 ohms in sending current around the circuit. If we apply 20 volts the amperes will amount to $20 \div 5$ or 4.

In a series circuit **the total ohms = the sum of separate resistances.**

To find the voltage across each one of the resistances in the previous example we apply Ohm's Law as usual: $4 \times 2 = 8$ volts across one, and $4 \times 3 = 12$ volts across the other. Across the whole combination the pressure = 4 amps. $\times$ 5 ohms = 20. This result is also found by adding the two voltages 8 and 12.

Pressure across a series of resistances equals sum of the voltages across the separate resistances.

In Fig. 3 a lamp of 31 ohms resistance is in series with a coil having 5 ohms. Current is supplied from a 120 volt generator through two line wires of 2 ohms each. What current flows and what pressure is used to force this current through the lamp? The total resistance is 40 ohms. Hence the current = 3 amperes. To drive 3 amperes through 31 ohms requires 3×31 or 93 volts, which is the pressure across the lamp.

Voltage Drop.—In this example we find the pressure across the lamp considerably lower than that supplied by the generator. There has been a

In this park in Portland, Oregon, 50 lamps of 400 candle power each are connected in series. The lamp at the left of the center takes 6.6 amperes; how much is taken by the lamp farther along the walk? The voltage across each lamp averages 37 volts; what is the drop in the line wires if the current leaves the substation at 1880 volts? What is the resistance of the line and of each lamp?

drop in the voltage from 120 to 93, or 27 volts. This may also be calculated by Ohm's Law. The resistance of the circuit between the generator and the

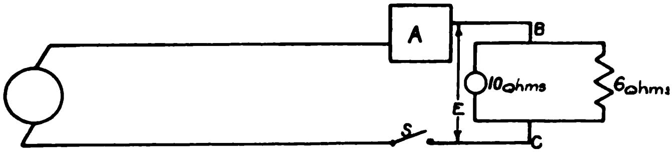


Fig. 4.—Resistances in Multiple. The current divides between the lamp and the resistance coil, 3 amperes being carried by the one, 5 by the other.

lamp totals 9 ohms. The pressure necessary to force the 3 amperes through this is, of course, 3×9 or 27 volts.

This municipal Christmas tree in a California city was lighted by 70 lamps in parallel. Each lamp took .23 ampere and the circuit voltage was 110 at the tree. The current was brought from a transformer on two wires of .12 ohm each. Can you calculate the resistance of each lamp, the combined resistance of all of them, the voltage drop in the wires and the voltage at the transformer?

The voltage drop in any conductor equals the pressure required to force the current through its resistance.

The drop between a generator and its load depends, then, upon both the line resistance and the number of amperes.

Resistances in Multiple.—When several lamps are located in one lighting fixture they are generally not connected in series with each other. Though

Two 400-horsepower motors are connected in multiple on the same power circuit. They are furthermore "direct connected" to the same shaft, so that the load is divided equally between them and the motors take equal currents. They lift the mine hoist at the South Eureka gold mine on the Mother Lode in California.

they are all governed by one wall switch, any lamp can be burned out or unscrewed without affecting the others. In a series circuit this could not be done.

In Fig. 4 we have a simple example of two resistances, a lamp and a coil, connected in "multiple" with each other; that is, connected so that the current flowing through the ammeter divides and part goes through the lamp and part through the coil.

Either can be disconnected without stopping the current in the other. This arrangement is sometimes spoken of as a "shunt" connection or a "parallel" connection.

Suppose that there is a pressure of 30 volts between the line wires at point E, close to the load. This is a measure of the effort to send current

These two fans operate in multiple on the same circuit. Hence either can be turned off without stopping the other. If the line current is 5 amperes at 110 volts when both are operating, what is the voltage and amperage for each motor? What is the resistance of a heater which takes as much current as three fan motors?

through the lamp and, if the lamp has 10 ohms resistance, it will carry a current of 3 amperes. The same pressure tends to send current through the coil, and, if that has 6 ohms, it will carry 5 amperes. The ammeter will read the sum of these two currents, 8 amperes.

In a multiple circuit **the voltage is the same across every branch; total current equals the sum of the branch currents.**

Combined Resistance.—As the combination of resistances shown in Fig. 4 takes more current than either one alone, we realize that the combination offers less resistance to current flow than either of its parts. Considering the lamp and coil as united into a piece of apparatus with terminals at B andC, we may compute its resistance from Ohm's Law as volts $\div$ amperes : $30 \div 8 = 3.75$ ohms.

A standard way to calculate is to assume one volt applied to the circuit, add the currents which would flow, and divide their sum into the one volt. Trying this on Fig. 4 we have $1/10 + 1/6 = 16/60$, the combined current. The resistance $= 1 \div 16/60 = 60/16 = 3.75$ ohms.

In a multiple circuit **combined resistance is less than ohms in any one branch; combined resistance $= 1 \div$ sum of reciprocals of branch resistances.**

III

POWER—LOSSES—EFFICIENCY

In stating the "power" of a motor we tell not only **how much** the machine can do but also **how quickly** it can do it. A single horse is able to haul an automobile to the top of a certain long hill, but it takes a 40 horsepower engine to perform the work in five minutes. We have, then, two factors which determine the amount of power, the force required and the rate at which it drives the load.

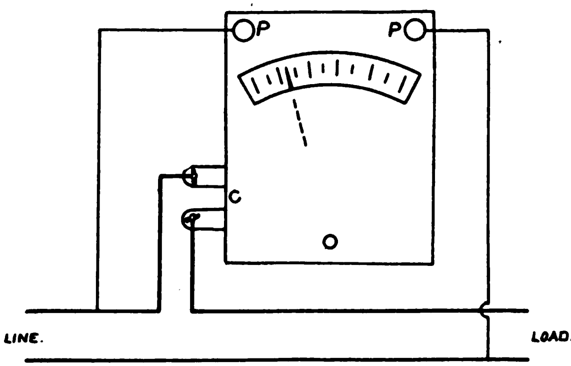


Fig. 5—Metering electric power with a watt meter. The reading depends both upon the volts (see connection to the pressure coil, P) and upon the amperes (see connection to the current coil, C).

In an electric circuit we have what corresponds to a force (the "voltage" or "pressure") and a quantity of electricity which is driven through the wires by this electromotive force. The rate at which the electricity is carried is indicated by the number of amperes of current, or "coulombs per second." Both

the voltage and the current, then, are factors in the power necessary to force electricity around a circuit.

It has been agreed that the simplest practical unit of power would be that required to drive one ampere by a pressure of one volt. This unit is called the "watt" in honor of the man who gave the world its first notions of power. Then if one volt drives current at the rate of 3 amperes, the power is 3 watts. If it takes 2 volts to drive 3 amperes, the power is twice as much, or 6 watts. In general, the number of watts equals the product of the number of volts times the number of amperes.

This statement holds good in direct current circuits and in those alternating current circuits which include no coils, condensers or long parallel lines. With one or more of these, there are reactions which reduce the power requirement below the number of "volt-amperes." The following expression is correct in all cases:

Watts $=$ volts $\times$ amperes $\times$ power factor,

where the "power factor" is equal to one or less, generally expressed as a percentage. It varies from 60% to 90% in most cases of alternating current motors and transformers, and is 100% for heaters, resistance boxes, incandescent lamps, etc., and for all direct current circuits.

Watts, Kilowatts and Horse Power.—The direct current load carried by an average power house may be 2000 amperes at 550 volts. The output of the machines, then, equals $550 \times 2000 = 1{,}100{,}000$ watts. This is too large a number to be handled conveniently, and it is customary in all such cases to use a larger unit, namely, the "kilowatt," which equals 1000 watts. Then the load above is expressed as 1100 kw. (kilowatts). The general formula is:

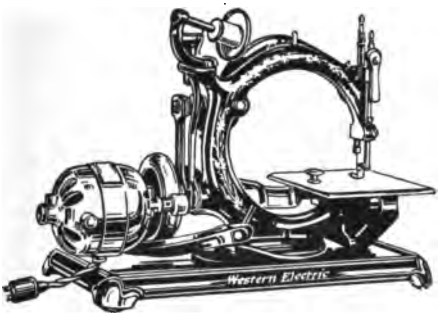
Kilowatts $=$ volts $\times$ amperes $\times$ power factor $\div$ 1000.

It is perfectly feasible to measure the power in electric circuits in terms of the "horse power," which was invented primarily for such machines as

the steam engine. It has been established by calculation and measurement that one horsepower equals 746 watts, or approximately ¾ kw. Thus it is possible to transfer quantities from one system to the other with little difficulty:

20 hp. (horsepower) = ¾ of 20, or 15 kw., and

50 kw. = 4/3 of 50, or 66.7 hp. (approximately).

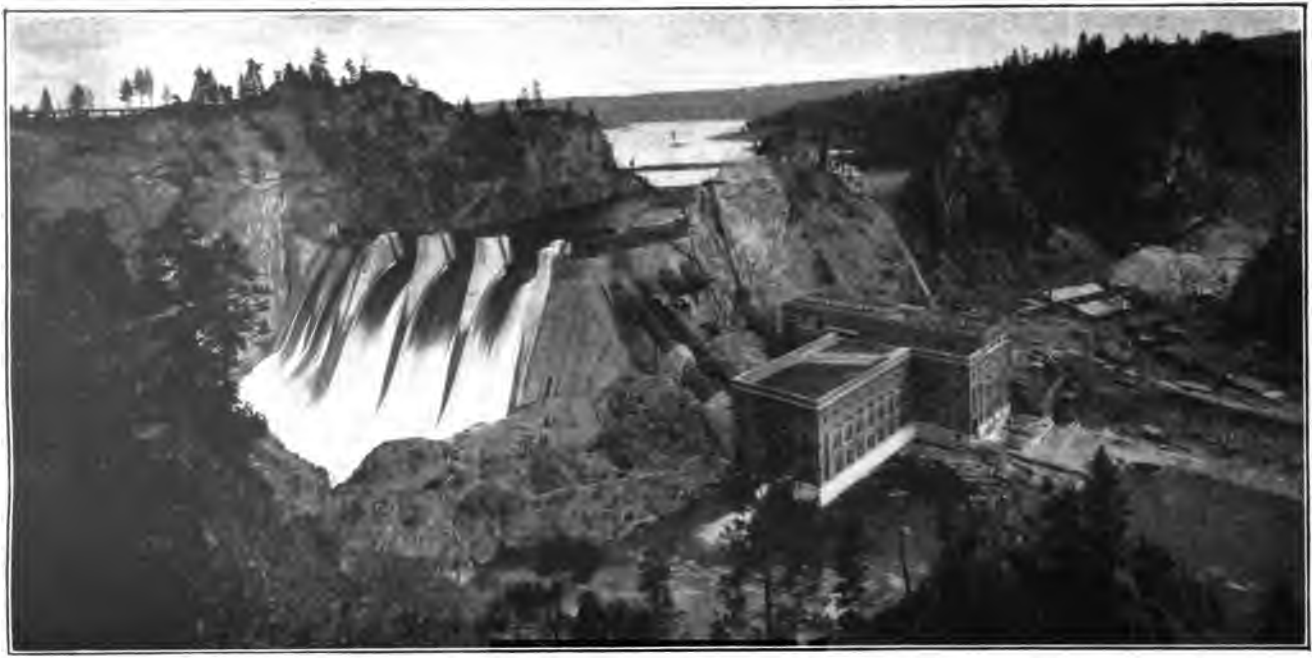


Among the many household uses for electric energy, one of the most convenient is illustrated here. With a certain piece of sewing in the machine the motor was found to take a current of 4 amperes, while a watt meter (connected as in Fig. 5) read .12 kw. What was the voltage of the d.c. circuit which supplied the current?

Power Measurement.—The horsepower output of a gas engine is conveniently measured mechanically by making it move a load. One horsepower is required to lift one pound at the rate of 550 feet per second, or to lift 550 lbs. one foot per second. For calculation,

Hp. = pounds pull × feet per second ÷ 550.

Electric power may be measured either by means of a wattmeter, connected as shown in Fig. 5, or by a combination of ammeter, voltmeter and power factor meter. The power factor meter is, of course, not used with circuits which are known to have 100% power factor. The wattmeter has both a "pressure coil" (terminals at P in Fig. 5) and a "current coil" (terminals at C), and their reaction upon each other determines the reading, which is thus proportional to both volts and amperes. On



LONGLAKE DAM, WASHINGTON

Hydraulic energy is converted to electric energy in this power plant, situated near Spokane, Wash. The generators when they are all installed will give a combined output of 56,000 kw. If their efficiency averages 92%, what will the input be? What will then be the hydraulic horsepower received by the turbines, if their efficiency is 85%?

a.c. (alternating current) circuits the wattmeter is able to take account of power factor also.

Losses and Efficiency.—The voltage at the generator end of a short d.c. (direct current) transmission line is 250 volts. At the receiving end a voltmeter reads 230 and an ammeter reads 50. The

This heater has a resistance of 27.5 ohms. What current does it take on a 110 volt circuit? How many watts of power? How many kw.? How many electrical horse power?

voltage drop is then 20 volts. The power given the line by the generator $= 250 \times 50 = 12500$ watts or 12.5 kw. That delivered by the line $= 230 \times 50 = 11500$ watts or 11.5 kw. There is a loss of power of one kw. which is used up in forcing the current through the wires.

Such a loss always occurs, and it results in heating the wires, just as the energy expended in moving a train changes to heat in the parts where there is friction.

It is possible to calculate the watt loss in a d.c. circuit by multiplying the voltage drop in the line by the current, as the watts in any part equal volts across that part times amperes. Thus in the example above we find $20 \times 50 = 1000$ watts. Further-

more, since the volt drop equals ohms $\times$ amperes, the watt loss = ohms $\times$ amperes $\times$ amperes, or the product of resistance times the square of the current. This last is a most important relation, and it applies to all circuits, both d.c. and a.c.

When we speak of the "efficiency" of a transmission system we have in mind a comparison of the power delivered with power put into the line at the generating end. Strictly, the efficiency is the number found by dividing the "output" of the line by the "input." As an example, consider a system which delivers 9,000 kw., the current being 800 amperes and the total line resistance 3 ohms. The loss = $3 \times 800 \times 800 = 1{,}920{,}000$ watts, or 1,920 kw. The input to the line $= 9{,}000 + 1{,}920 = 10{,}920$ kw. Then the efficiency of transmission $= 9{,}000 \div 10{,}920 = .824$, which is 82.4%.

A mechanical machine, such as a waterwheel, may give out 40 h.p. while receiving 50 h.p. from the water. Its efficiency $= 40 \div 50 = 80\%$. No machine has ever been made with efficiency as great as 100%, for some of the energy put in is always lost by friction. No transmission of electricity is 100% efficient, for energy is always converted into heat in overcoming resistance.

IV

ELECTROMAGNETS—TRANSFORMATION OF ENERGY

A soft iron bar with a coil of wire around it becomes a magnet when current flows through the wire. The magnetism disappears when the current stops, so that whatever had been picked up now falls away. A similar "electromagnet" may be made without any iron, but the pull it exerts is far less.

Magnetic effects are explained on the theory that an electromagnet or a permanent steel magnet produces "lines of force" which issue from one end or "pole" and return to the other end, and then pass through the instrument itself. Thus each line of force is a complete, closed curve.

The end of the magnet out of which the lines come is called the "north pole" for it is found that, whenever it is so supported as to be free to turn (as by floating it upon a cork or balancing it upon a pivot), this end turns toward the north. The force lines (often called "magnetic flux") enter the magnet at the "south pole," after passing through the air or any iron or steel objects in the neighborhood.

Magnetic flux runs through all substances, but far more easily through iron and steel than any other material. Thus a current flowing in a simple coil produces lines of force, but with an iron core in the coil many more lines are found. And if an iron path is provided for the lines outside the magnet, so they do not have to go through any other material, a large flux can be produced with a small current.

Hence, electromagnets are often made in the shape of a horseshoe, and iron paths are provided for the external flux in such electromagnetic machines as generators and motors.

The amount of flux produced by a magnet depends upon the number of turns in the coil and upon the current, as well as upon the material the lines traverse. It is found that 8 amperes through 20 turns give exactly the same flux as 40 amperes

This is a hand magnet used in various ways such as the handling of hot castings, removing iron and steel from materials for making solder and recovering nails from sweepings.

through 4 turns. In other words, the product of amperes $\times$ turns (which is called the "ampere-turns") determines the tendency to produce flux, while the number of lines actually set up depends also upon the nature of the magnetic path.

Ammeters.—Applications of electromagnetism are found in the ammeters used for measuring currents on switchboards and elsewhere. One type is illustrated in Fig. 6, which shows the d'Arsonval movement found in one type of ammeter. When the current to be measured flows around the coil attached to the pointer, the coil becomes a magnet with each face one pole. These are attracted to the opposite sides of the permanent steel magnet constituting the frame, which causes the coil to turn against the restraint of springs. If the current increases, the turning effort becomes stronger, so that the pointer is carried farther along the scale.

The Kilowatt Hour.—If a man uses 3 kw. for four hours he makes only half as much demand on the power company as if he used 3 kw. for eight hours, and he gets only half as much work done by his motor. In one case he uses 4×3 or 12 "kilowatt-

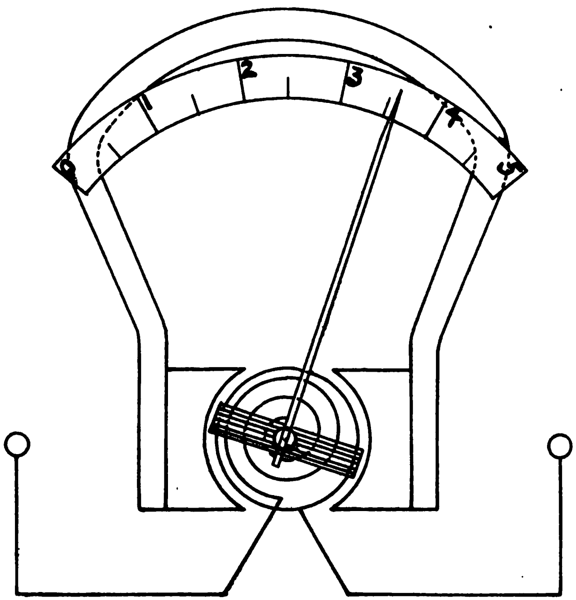


Fig. 6.—Current entering the ammeter through the spiral spring makes the coil and its iron core an electromagnet

hours" of electrical energy, and in the other case 8×3 or 24 kw-hr. The cost of electric service depends on both the power and the time; the usual custom is to base the charge on the "kilowatt-hour," which is the energy supplied in one hour by one kw. The retail price of one kw-hr. varies from one to 5 cents for heating, cooking and motors, and from 6 to 15 cents for lighting. Energy is sometimes sold by the horsepower-hour (¾ of a kw-hr.), and sometimes by the horsepower-year (especially for pumping irrigation water).

At 6 cents per kw-hr. $1.80 will buy 30 kw-hr. The power may be 30 kw. for 1 hour; or 10 kw. for 3 hours; or 6 kw. for 5 hours; or ½ kw. for 60 hours; or 4 kw. for 3 hours and 9 kw. for 2 hours. Evidently a statement of a number of kw-hr. does not tell anything at all about the number of kw. (or power). Instruments that measure kw-hr. are not "watt-meters" but "watt-hour meters."

WESTERN ELECTRIC HOT PLATE AND KLAXON HORN

Here are two devices for transforming electric energy into other forms—sound in the Klaxon horn and heat in the hot plate. The latter takes 4 amperes on a 220 volt circuit—how many British thermal units will it give out in an hour? If one-half of the heat escapes to the air, how hot will a gallon of water (8 lbs.) get in half an hour if its temperature is 60° when it is set upon the hot plate?

If you know the kw-hr. and the number of hours, you can find the average kw. In the example above, if it is given that the 30 kw-hr. are used in 5 hours we can say that the average power is 6 kw. —but it may be 4 kw. for 3 hours and 9 for 2 hours. Note the particular meaning of the word "average" here; average kw. = number of kw-hr. divided by the number of hours.

Heat Energy.—It has been found by numerous careful experiments that when one kw-hr. of electrical energy is used up in overcoming "electrical friction" or resistance, a certain definite amount of heat is developed, namely, enough to heat 3,412 pounds of water one degree hotter (by Fahrenheit thermometer). This is generally expressed by saying that 1 kw-hr. = 3,412 "British Thermal Units" or 3,412 B.t.u. Also when one kw-hr. of mechanical energy (1 1/3 h.p. hours) is used up in overcoming

This is the largest gold dredge in the world. It is located near Hammonton, California, and is electrically operated throughout, with its chain of 18 cu. ft. buckets handling 15,000 cu. yds. of gravel a day at a cost of only three cents per cu. yd. What horsepower is required to move the gravel up the "bucket ladder" in this gold dredge when the pull up the slope is 20,000 lbs. and the speed 15 feet per second?

friction 3,412 B.t.u. of heat is developed. One horse-power-hour similarly gives 2,545 B.t.u.

In a steam or gas engine it is possible to measure the heat developed by the fuel and the heat wasted in the exhaust, radiation, etc. The loss of heat is always less than the heat developed, the difference being a certain definite number of B.t.u. in each case. It is found that this difference, divided

INSIDE THE FARM HOUSE

This installation of an electric range and an electric water heater in a ranch home in California uses $6.00 worth of electric energy per month at a rate of 3 cents per kw-hr. What was the average current taken, if the apparatus was used on a 110 volt circuit 5 hours a day for 30 days?

by 2,545, gives the number of h.p. hours of mechanical energy developed. Or, the "useful" B.t.u. divided by 3,412 = the number of mechanical kw-hr. Thus it is proved that 3,412 B.t.u. can be changed to 1 kw-hr., or 1 kw-hr. can be changed to 3,412 B.t.u. Mechanical energy, electrical energy, and heat are simply three forms of the same thing; by various devices we can make energy take any form desired.

Efficiency of Transformation.—In many transformations of energy, there is a "loss" of some of

the energy—loss in the sense that the energy changes into some form that is not desired, or goes to some place where it is not wanted. For example, in a motor we wish electrical energy to be converted to mechanical, but inevitably some energy goes into heat through friction, resistance in the wires, etc. If the motor has an efficiency of 80%, 20% of the electrical input is expended in undesired ways. Similarly, in an electric water heater we desire the conversion of the electrical energy into heat **in the water,** but some heat is sure to escape to the surrounding air, material of the container, etc. The efficiency of such a device = useful B.t.u. ÷ total B.t.u. produced from the electrical energy; or eff. = useful B.t.u. ÷ 3,412 × kw-hr. expended. On the other hand, an electric air heater in a room has perfect or 100% efficiency, for **all** the heat must get into the air and objects where it is wanted.

Engines which are used for the purpose of converting heat into mechanical energy are comparatively inefficient. A large part of the heat given to them is sent out again as heat and not as work. Most of it goes out through the exhaust, but in many cases (as in gas engines) a large part of the heat is passed out through the cylinder walls to the cooling water. The efficiency of steam and gas engines in practice varies from 10% to 30%.

V

WIRE CALCULATIONS

Wires used to carry electricity are usually of copper, aluminum or iron. In the United States copper and aluminum wires are made in various sizes according to an arbitrary set of dimensions known as the "Brown & Sharpe (or American Standard) Wire

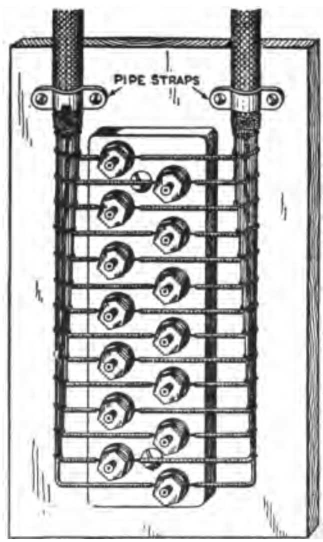


Fig. 7.—Connecting block for an interior telephone system. If each wire is No. 18, what is the resistance of 200 feet of the cable if all the wires are connected together at each end?

Gage." A wire known as No. 5, for example, has a diameter of .1819 inch, and No. 10 has a diameter of .1019 inch. The largest size in this gage is No. 0000, the next is No. 000, then 00, then 0, then Numbers 1 to 40, of which the last is the smallest wire (.00315 inch diameter).

It is customary to express the diameter in "mils" (one mil = .001 inch) rather than in inches. Then No. 5 wire is 181.9 mils thick, and No. 10 is 101.9 mils thick. The cross section area of a wire can not be expressed conveniently in square inches; it is found preferable to use, instead, the "circular mil" (c.m.) as a unit. For wires and cables larger than No. 0000 the size is designated by their circular mil area. The diameter of a solid wire is found by taking the square root of its c.m. area. When the diameter is known, the c.m. area is found by squaring the number of mils in the diameter.

Wire tables are found in all electricians' text books and hand books. From these one can quickly determine the characteristics of copper wire of any size. The tables differ somewhat in arrangement, but practically all of them give the diameter and the section area for each numbered size, together with the resistance and the weight of 1000 feet of wire. The partial table on p. 32 gives figures for a number of sizes of copper and aluminum wire.

If one knows that the resistance of one foot of 36 wire is .414 ohm, it is easy to compute the resistance of any length. Six feet, for instance, will have 6 x .414 or 2.484 ohms, for we have six resistances of .414 ohm each connected in series. Then the resistance of 220 feet of No. 18 copper wire is 220 times 1/1000 of 6.374 (see table), for 6.374 ohms is the resistance of 1000 feet.

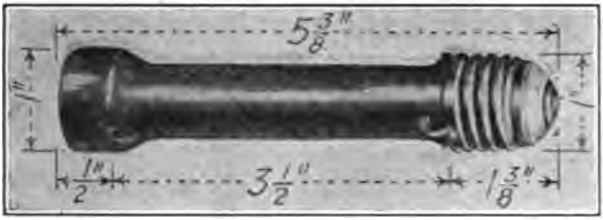
The weight of any length of bare wire is figured in exactly the same way from the tabulated figures of the lbs. per thousand feet. Manufacturers and dealers supply with price lists tables of the weights of wires insulated in various ways.

In the table below the resistances are given for a temperature of 68° Fahrenheit. For any other temperature the figures are incorrect, since the resistance of metals increases with rising temperature. For copper and aluminum the ohms increase about 0.2% for each degree, so that at 88° the resistance is 4% greater than indicated by the table.

PARTIAL WIRE TABLE

Gage Number B&S	COPPER						ALUMINUM			
	Diameter in Mils	Area in Cir. Mils	Ohms per 1000 Feet	Lbs. per 1000 Feet	Safe Amps. Other Ins'n	Safe Amps. Rubber Ins'n	Ohms per 1000 Feet	Lbs. per 1000 Feet	Safe Amps. Other Ins'n	Safe Amps. Rubber Ins'n
0000	460.0	211600	.0489	640.5	325	225	.0804	192.0	273	189
000	409.6	167800	.0617	508.0	275	175	.1014	152.3	231	147
00	364.8	133100	.0778	402.8	225	150	.1278	120.8	189	126
0	324.9	105500	.0981	319.5	200	125	.1610	95.9	168	105
1	289.3	83690	.1237	253.3	150	100	.2032	76.0	126	84
2	257.6	66370	.1560	200.9	125	90	.2562	60.2	105	75
3	229.4	52630	.1967	159.3	100	80	.3230	47.8	84	67
4	204.3	41740	.2480	126.4	90	70	.4075	37.9	75	59
5	181.9	33100	.3128	100.2	80	55	.5140	30.0	67	46
6	162.0	26250	.3944	79.46	70	50	.6480	23.8	59	42
7	144.3	20820	.4973	63.02			.8171	18.9		
8	128.5	16510	.6271	49.98	50	35	1.050	15.0	42	29
9	114.4	13090	.7908	39.63			1.300	11.9		
10	101.9	10380	.9972	31.43	30	25	1.640	9.42	25	21
11	90.74	8234	1.257	24.93			2.068	7.47		
12	80.81	6530	1.586	19.77	25	20	2.605	5.93	21	16
13	71.96	5178	1.999	15.68			3.284	4.71		
14	64.08	4107	2.521	12.43	20	15	4.250	3.73	16	12
15	57.07	3257	3.179	9.86			5.111	2.96		
16	50.82	2583	4.009	7.82	10	6	6.591	2.34	8	5
18	40.30	1624	6.374	4.92	5	3	10.49	1.47	4	2.5
20	31.96	1022	10.14	3.09			16.66	.929		
22	25.35	642	16.12	1.95			26.51	.581		
24	20.10	404	25.63	1.22			42.15	.367		
26	15.94	254	40.75	.769			67.05	.230		
28	12.64	160	64.79	.484			106.5	.144		
30	10.03	100	103.0	.304			169.3	.091		
32	7.95	63	163.8	.191			269.5	.057		
34	6.31	40	260.5	.120			428.5	.036		
36	5 00	25	414.2	.076			681.0	.023		
38	3.97	16	658.5	.048			1084.	.014		
40	3.15	10	1047.	.030			1722.	.009		

Allowable Current. — Wires carrying current become heated, and the temperature rises until the loss of heat to the surroundings equals the heat developed. Then the temperature remains stationary. The hotter the wire becomes, the more heat it



For replacing carbon lamps in "lamp banks" used as rheostats, these resistor units are being used. This particular one absorbs 60 watts at 120 volts. What length of No. 36 copper wire has an equal resistance? What length of No. 36 nichrome?

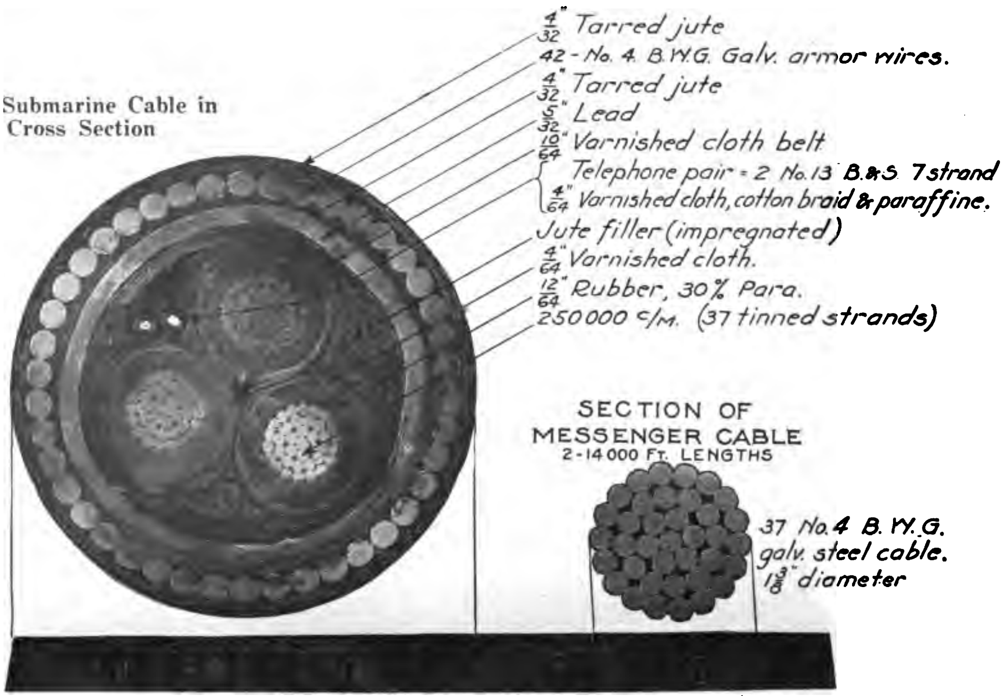
can give off per second, so that (unless it is surrounded by a non-conductor of heat like asbestos) the temperature of a wire depends upon the watt loss in it, which in turn depends upon the current.

The insulation upon conductors used in inside wiring will deteriorate if exposed to heat, and hence the temperature rise of the wires must be strictly limited. The National Board of Fire Underwriters issue in the "National Electric Code" a table of the current to be allowed in copper wires used for

This vacuum cleaner hose must carry a large current of air with little resistance. Hence it is made as large as practicable. What would be the loss of pressure in a similar tube twice as long?

interior wiring. This is given in the wire table accompanying this lesson. Note that the current in rubber insulated wire must be kept smaller than in wires with other insulations, on account of the fact that rubber deteriorates at lower temperature than other insulations.

Submarine Cable in Cross Section



This cable carries current 26,775 feet across the Golden Gate for the Pacific Gas & Electric Company. What is the resistance of each of the 250,000 circular mil conductors? What is the voltage at the other end of the telephone pair if 40 volts are applied at the San Francisco end and a current of .3 ampere is allowed to flow?

Aluminum, Iron, and Other Wires.—Since aluminum has a lower conductivity than copper, wires of aluminum must be larger than copper wires for the same current. But its density is so much lower than that of copper that the larger aluminum wire weighs much less than the copper it replaces. Knowing the size of copper needed for a certain load, one can select an aluminum wire two sizes larger (in the B. & S. gage) and figure the weight as ½ that of the copper.

Iron wire, used to some extent for telephone lines, has much higher resistance than copper or aluminum. It is manufactured in sizes different from those in the B. & S. gage, the system followed being called the "Birmingham wire gage." The grade known as "Best Best" (B.B.) has the following characteristics in two sizes much used:

No. (B.W.G.)	C.M.	Lbs. per mile	Ohms per mile
9	21904	314	17.84
14	6889	99	56.56

Suppose that No. 14 B.B. wire is to be used to make a resistance for an arc lantern. If the line voltage is 110, the pressure across the arc 70 volts, and the current to be used is 18 amperes, how many pounds of wire should be bought? The drop in the wire = 110—70 = 40 volts; the resistance = volts/amperes = 40/18 = 2.22 ohms. The table gives the ohms per mile for No. 14 as 56.56, hence the ohms per foot = 56.56/5280 = .0107; 2.22/.0107 = 207, the number of feet of wire. The lbs. per mile is given as 99; 99/5280 = .0187 lbs. per foot; hence our wire weighs 207 × .0187 lbs. or 3.88 pounds.

When resistance is desired, it is usual to take instead of iron a wire of some composition, such as "German Silver," "Climax," or "Nichrome." The German silver is an alloy of copper, zinc and nickel; most other special resistance materials are alloys of steel with nickel, etc.

These materials are made into flat and square conductors and round wires, the B. & S. gage being

generally adopted for the round wires. To calculate the resistance of any wire, find the ohms of a piece of copper wire of the same size and length, and multiply by the proper multiplier: for Nichrome multiply by 60; for Climax multiply by 50; for German Silver (ordinary, with 18% nickel) multiply by 20; for Brass multiply by 4.4; for Aluminum Bronze multiply by 7.5; for Steel multiply by 8.3. To find the weight of Nichrome wire multiply the weight of a similar copper wire by .92; for Climax multiply by .92; for 18% German Silver multiply by .95; for Steel multiply by .88.

VI

THE GENERATOR

Faraday's Discovery.—As shown by the electromagnet, an electric current can produce magnetism; it was to be expected that electric current could be produced from a magnet. After many fruitless efforts Faraday in 1831 discovered how to do it; with the arrangement shown in Fig. 8 he succeeded in causing a flow of current through the sensitive ammeter whenever he moved the magnet into or out of the coil. The current stopped as soon as the movement stopped; leaving the magnet in the coil produced no current. But moving the coil off the magnet while the latter was held still caused the current to flow just as if the magnet itself had moved.

The effects produced by moving the magnet or the coil may be said to be caused by the cutting of the wires by lines of force. As soon as the cutting stops, the circuit is dead. The current through the ammeter depends upon the resistance of the connecting wires as well as upon the motion of the magnet; so it is better to replace the ammeter by a voltmeter and make further investigations of the phenomenon on the basis of electromotive force.

This e.m.f. is said to be "induced" by the magnetic lines, just as pieces of iron acquire "induced magnetism" in the neighborhood of a magnet.

Experiments with coils of various numbers of turns, with magnets moving slowly and rapidly, and with magnets of different strengths, lead to this conclusion: The induced e.m.f. depends upon the number of lines of force, the speed with which they cut the wire, and the number of turns of wire in series . (A strong magnet has, of course, more lines of force than a weak one.) It was found possible to

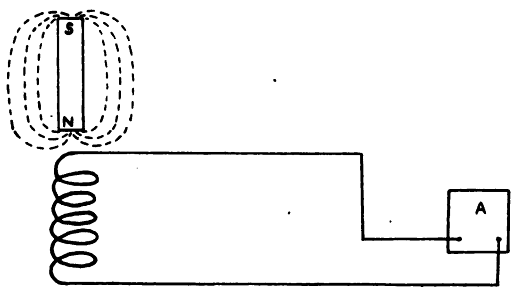


Fig. 8.—The details of Faraday's arrangement for causing a flow of current through an ammeter by moving the magnet into and out of the coil.

get a definite numerical statement, as will be explained later in connection with the voltage of generators.

Faraday's apparatus always produced an alternating voltage; pulling out the magnet induced an e.m.f. opposite to that caused by putting it in. Inserting the S pole induced a voltage opposite to that caused by inserting the N pole. The only way to get a current through the ammeter of Fig. 8 continuously in the same direction is to reverse the connections with every movement of the magnet.

The A.C. Generator.—On account of the mechanical advantages of rotary over reciprocating motion, generators are built commercially with either the magnets or the coils revolving. Fig. 9 gives a general idea of the arrangement of a "revolving field" alternator. We have here a magnet turning on a shaft so that the lines of force close to its poles cut across the stationary wires A and B. The N pole induces in wire A a voltage directed toward the back

of the machine, while in B the S pole sets up an e.m.f. in the forward direction. The wires are joined at the rear and connected to a lamp in front, which at the instant shown has current flowing in it from right to left. When the poles are turned far enough to exchange places, the electromotive force is again induced but in the opposite direction, so

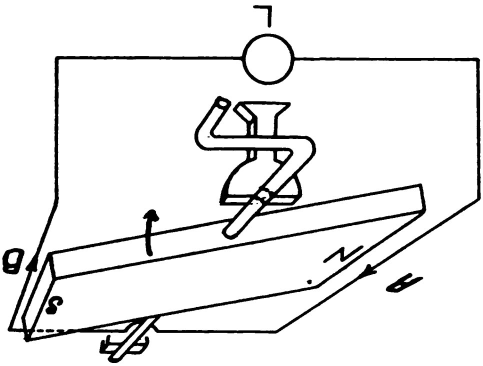


Fig. 9.—The plan of the "revolving field" alternator. At the instant shown the lamp has current in it from right to left

that the current flows from left to right in the lamp, having stopped when the magnet was halfway between the two positions. Thus is produced an alternating current, which might be "rectified" so as to flow always in the same direction through the lamp by reversing the lamp connections twice in each revolution of the magnet.

The "revolving field" usually contains, instead of a single permanent magnet, a number of strong electromagnets. An iron ring is placed around the outside of the "inductors" (wires cut by the lines of force) so that the flux may get from pole to pole with as little difficulty as possible. Thus there is provided a large number of lines of force, and by turning the shaft rapidly it is possible to induce several volts in one inductor. Finally, a number of wires are connected in series, so that the generator produces any voltage desired.

The D.C. Generator.—A revolving field machine is not well adapted for producing direct currents. The d.c. generator in Fig. 10 has therefore a stationary field and revolving "armature." (The armature is the structure which includes the inductors and the iron core to which they are attached; the core is omitted from Fig. 10 for the sake of clearness.)

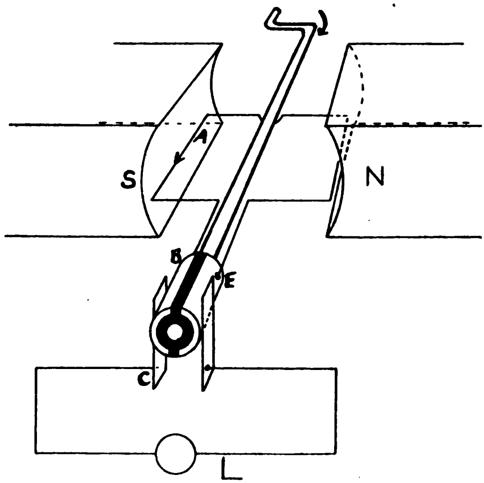
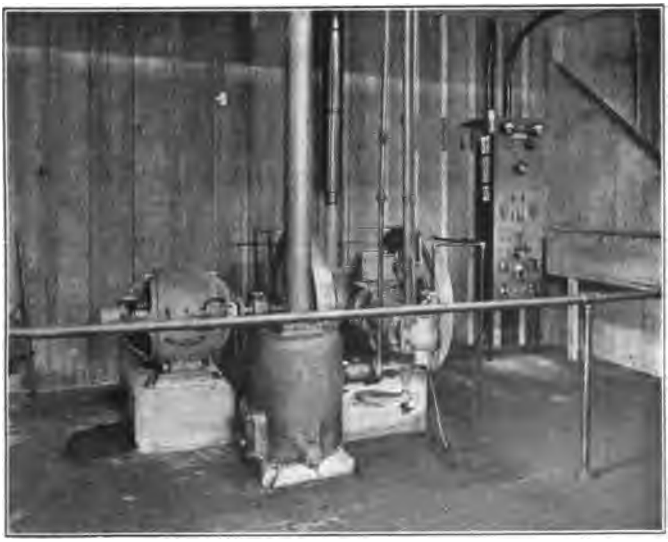


Fig. 10.—A d.c. generator with a stationary field and revolving armature for producing a direct current. In the position shown the wire A has induced in it a voltage directed forward, which drives current out of the armature through the sliding contact between a "segment" (B) and a brush (C). The segment B is attached to the armature and revolves with it, so that when A reaches a position close to the N pole it is in contact with the other brush, and segment E has come around to brush C. Thus the wire passing the S pole always sends current out to brush C, and so downward through the lamp, L.

With this simple arrangement the voltage drops to zero twice in every revolution. If a second coil were put on the armature at right angles to the first coil, it would have a strong e.m.f. when the first e.m.f. is zero. With the ring split into four parts instead of two, and the new coil connected to two of the segments, a fairly uniform pressure could be produced. In practice many coils are used on the armature and correspondingly many segments are built into the "commutator" as the split-ring device is called.

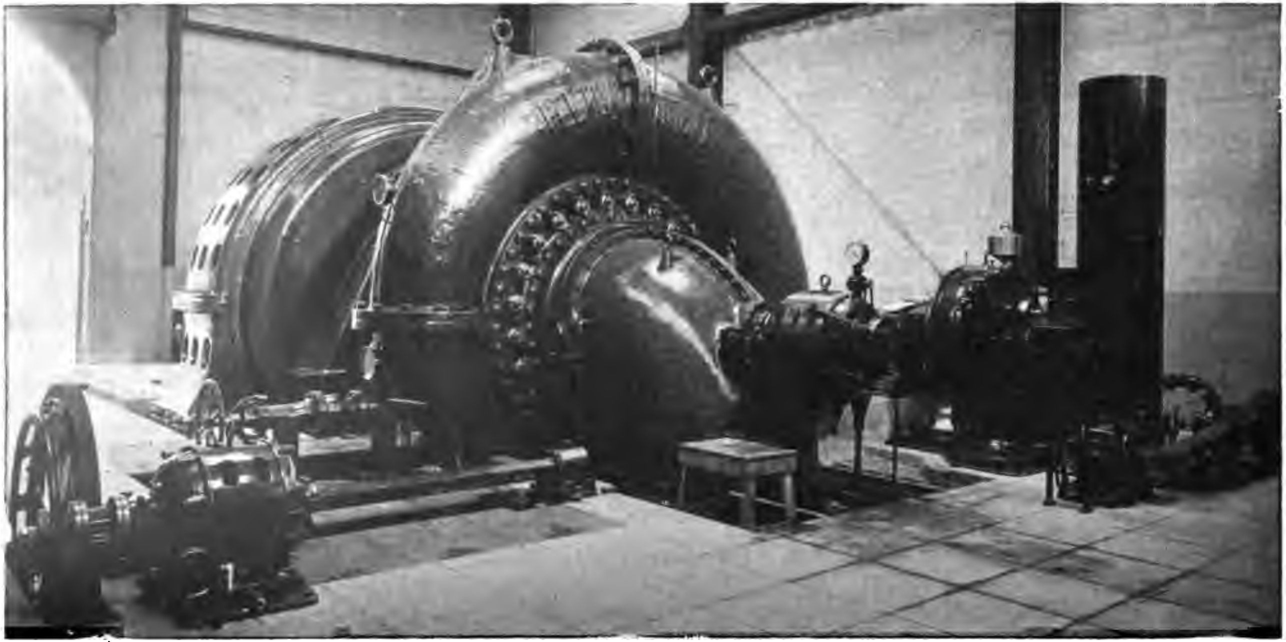
It should be clear that a d.c. generator produces an alternating current which is "rectified" or made into direct current by means of the commutator. Many d.c. machines are made with more than two poles; in these there are usually as many brushes as poles. Carbon is the material used in the brushes, chiefly because of its resistance which is useful in limiting the short circuit currents which



In a Columbia River salmon cannery this 6 kw., 120 volt d. c. generator produces all the current necessary to operate the lights and motors. It is driven by a 10 h. p. semi-Diesel oil engine. What is the efficiency of the generator and what current does it supply when fully loaded? How many pounds of oil are used in 8 hours if the average load is 40 amperes, the engine efficiency is 30% and the fuel gives 19000 B. T. U. per lb.?

tend to flow from one "bar" (segment) of the commutator to the next while the brush is touching both.

Generator Voltage.—It is customary to specify the strength of the magnets used in generators by the number of lines of force they produce. This system is, of course, based on an arbitrary standard, for a line of force is merely a convenient term to use in connection with magnets and it has no tangi-



The Wise power plant of the Pacific Gas & Electric Company contains the largest single discharge turbine in the world, with a possible horsepower of 20,000. Its efficiency is 87%. Behind it is an enormous a.c. generator with revolving field. Its efficiency is 96%. What is the input to the turbine in "hydraulic horsepower" when the generator gives out 12,000 kw.?

ble existence. In practice the electromagnets most used have from 100,000 to several million lines issuing from their N poles. It is to be noted that one inductor cuts across all these lines once when passing the N pole of a magnet and again when passing the S pole, so that the total number of cuttings during one revolution equals the product of the number of poles times the lines per pole.

The standards of pole strength and electromotive force have been so selected that one volt is the e.m.f. induced by cutting one wire in one second by 100,000,000 lines of force. Putting inductors in series adds their voltages, so that

Generator Voltage = No. Poles Passed per Second × Flux per Pole × No. Wires in Series ÷ 100,000,000.

This formula gives the average voltage for an alternating or fluctuating current, or the steady voltage in a d.c. machine. The number of wires in series may be the total number of inductors on the armature, or one-half that number, or one-fourth or one-sixth, or less. Direct current generators usually have enough coils and commutator segments to make the voltage practically constant at the value given by the formula.

VII

ARMATURE AND FIELD WINDINGS

Of all the types of generators, the simplest is the alternating current magneto, which is used for ringing telephone bells and for ignition in gas engines. The magnetic flux is supplied by one or more stationary permanent magnets of horseshoe shape. The armature generally consists of a single coil wound upon an iron core, which revolves between the magnet poles. One end of the winding may be

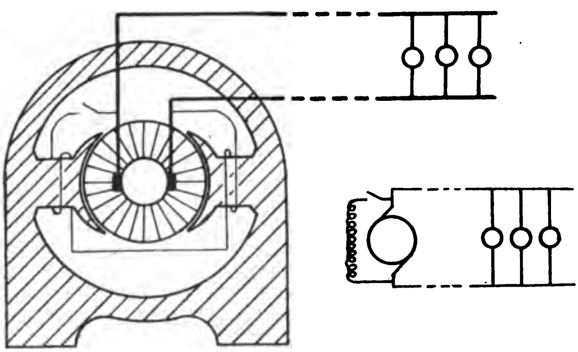


Fig. 11.—Shunt generator. Coils of small wire on the magnet poles are connected in multiple or shunt with the load.

"grounded" (connected to the metal of the armature) while the other is connected to the external circuit through a sliding contact.

All other generators have electro-magnets for producing the "magnetic field" or flux. The wires which carry the current around these magnets constitute the "field winding."

The magnets are "excited" by sending direct current through these windings, the current being produced either by the generator itself or by some external source. Direct current generators are almost always "self excited," while a.c. machines are "separately excited" by the use of small d.c. generators called "exciters." A few alternators have special arrangements for producing small amounts of direct current, thus saving the expense of an extra machine.

In Fig. 11 is shown the simplest arrangement for self excitation, a direct current machine with the field winding connected in multiple or "shunt" with the load. The diagram on the right is a preferable way to represent the same arrangement. Many turns of fine wire are used, which offer enough resistance to limit the field current to a small value, and yet give sufficient "ampere-turns" almost to saturate the iron with magnetism.

When the machine is stopped the current dies out of the shunt field and the magnetism disappears, with the exception of a small amount which is known as "residual magnetism"; that is, the iron has to a slight extent the characteristics of a permanent magnet. When the generator is again brought up to its running speed, it is found that a low voltage is produced, and if the shunt field switch is then closed, a small current is sent through the coils. This increases the magnetism and raises the voltage, which comes up, little by little, to the pressure for which the machine is designed.

To control the electromotive force of a generator, it is customary to insert a variable resistance or "rheostat" in series with the field winding. Thus the current and flux can be altered at will, and hence the voltage, which depends on the strength of the magnets, can be raised or lowered within wide limits. (See the rheostat, R, in Fig. 12.)

An additional feature of the field winding of most d.c. generators is shown in the "series winding" in Fig. 12. A few more turns of wire are put around

An early water power plant, built on Hunter Creek, Colorado, in 1888. Note the bipolar d.c. generator in the foreground, the multipolar machine at the left and the peculiar field arrangements of the generators near the brick wall.

the magnet poles and this wire (which is made of large size) is connected in series with the load. The additional magnetism thus produced raises the generated voltage as the current increases, and thus

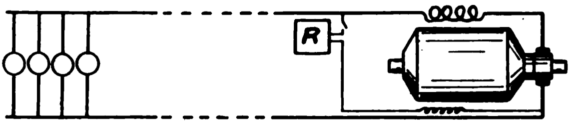


Fig. 12.—Compound wound generator. The load current passing through the series coils tends to raise the generated voltage as the load increases. The rheostat in the shunt circuit enables the operator to change the voltage at will.

compensates for the increased "line drop" at heavy loads. A generator thus equipped is said to be "compound wound."

The field coils of an alternating generator are connected to the exciter through a rheostat. If the alternator field revolves, it is necessary to get the

Voltage regulation by the shunt field rheostat is sometimes not sufficiently accurate. This series rheostat and ammeter are used to keep the current constantly equal to 20 amperes in the 600 watt gas filled lamp used in many moving picture projectors. What is the lowest possible generator voltage for this service?

current to and from the windings through sliding contacts on "slip rings." This is preferable to using sliding contacts for the generator current, which is usually at high voltage and of much greater volume than the exciting current.

Armature Winding.—Direct current generators usually have drum shaped armatures, built of many thin circular leaves or "laminations" of iron or steel. The wire is placed in slots cut lengthwise along the

cylindrical surface and connected at numerous points to the copper commutator bars.

In Fig. 13 is shown a very simple winding for a "bipolar" (2 pole) machine having 6 slots in the armature, 12 inductors and 6 commutator bars. The letter B indicates the bar in contact with one of the brushes—let us say the "positive" brush, or the one at which the current leaves the armature. Then the current enters the winding at A, and flows along the wires to inductors numbered 1 and 7, both of which

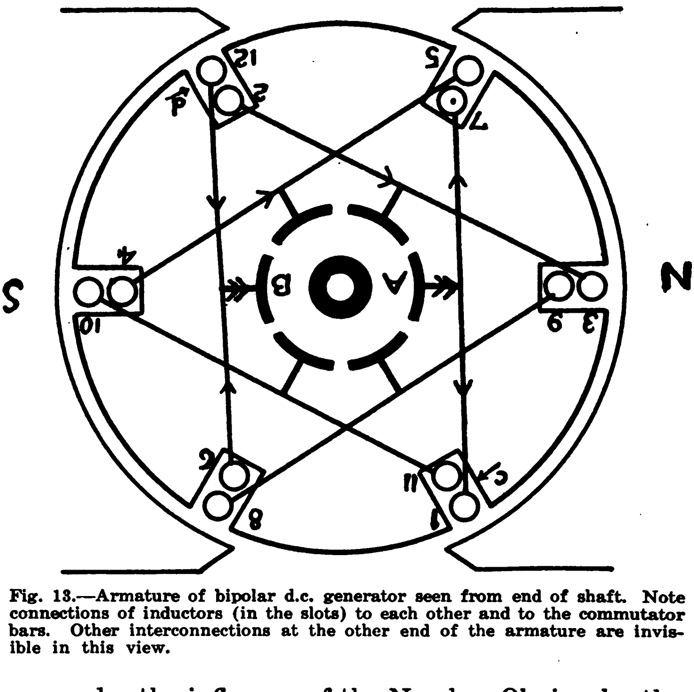


Fig. 13.—Armature of bipolar d.c. generator seen from end of shaft. Note connections of inductors (in the slots) to each other and to the commutator bars. Other interconnections at the other end of the armature are invisible in this view.

are under the influence of the N pole. Obviously, the machine must be turning in such a direction that voltage in wires under the N pole is directed into the paper, or away from the observer. Similarly, the inductors under the S pole must urge the current "out" or toward the observer.

Now we must imagine a wire across the back of the armature which carries the current from the far

end of inductor No. 1 to the far end of No. 2. The pressure generated in No. 2 then assists that of No 1, and the current is forced along the wire shown, across the front end of the armature, to inductor No. 3, passing a commutator bar which is inactive because out of contact with either brush. The current flows "in" along No. 3, across the back of the armature to No. 4, across the front to No. 5, then across the back to No. 6, finally reaching bar B and leaving the armature. Six inductors in series have

This shows how the formed coils are placed on the armature and the terminals connected to the risers from the commutator bars.

added their voltages, so that if the average pressure induced in each is .9 v., the machine generates 5.4 v.

The other inductors, commencing with No. 7, and working through Nos. 8, 9, 10, 11 and 12, perform a service exactly similar to that of the first set, producing a voltage of 5.4 in parallel or multiple with the first voltage considered. If the current is 5 amperes in each wire, the total current sent out of Bar B is 10 amperes. Thus we have the armature current twice that in one inductor, and armature voltage equal to the product of half the inductors times the average e.m.f. in one.

Generators with 4, 6 or more poles are not uncommon. The armatures may be so wound that there are only 2 parallel paths for the current or so that there are as many paths as poles, or with other numbers dependent upon variations in the methods of connection. With the "lap" or "multiple" winding there are at least as many paths as poles, and there must be as many brushes as poles. With "series" or "wave" winding there are, in general, only two parallel paths, and there may be either 2 brushes or as many brushes as poles.

There are often more than 2 inductors in one slot, especially in small machines. This necessitates cross connections on the front end of the armature in addition to those running to the commutator bars. Referring to Fig. 13, the wire might run "in" along the top of slot **c**, then across the back and "out" along the bottom of **d**, then across to slot **c** again (avoiding the commutator) and thus through **c** and **d** several times. The coil may be wound on a "form" and taped and varnished before being put upon the armature, and this is the usual practice for "multipolar" machines (having 4 or more poles).

The armature of Fig. 13 could be made to produce alternating current by taking away all the commutator bars except A and B and changing each of these to a "slip ring," so that each would be continuously in contact with the same brush.

VIII

LOSSES AND REACTIONS IN D.C. GENERATORS

Copper Losses.—When a d.c. generator is sending current through a line and a load, as in Fig. 14, the number of amperes is found by dividing the generated voltage by the total ohms of the circuit, which means the sum of the resistances of the load and the line plus the resistance in the armature, commutator and brushes. It is to be emphasized that the

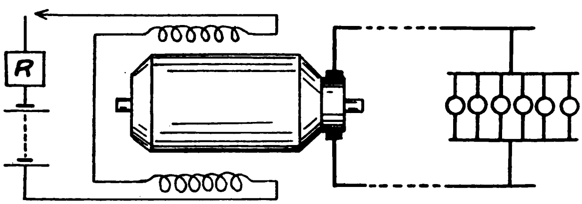


Fig. 14.—Separately excited d.c. generator.

electromotive force has to overcome resistance in the generator as well as in the external circuit. Thus there is a conversion of electric energy into heat energy in the inductors, the watts wasted here being termed the "armature copper loss." It is calculated by multiplying the armature resistance by the square of the number of amperes flowing through it; in Fig. 14, this is the same as the line current, but in Fig. 16 it is greater by the amount of current used in the shunt field.

One can measure the resistance of an armature by sending a small current through it, measuring the voltage drop, and calculating by Ohm's law.

The resistance of an armature may also be determined from the size and length of the wire used in winding.

As shown in Fig. 15, an armature coil may consist of a single turn of wire, running from one commutator bar to and through the top of one slot, then across the back of the armature and forward through the bottom of another slot to the bar adjacent to

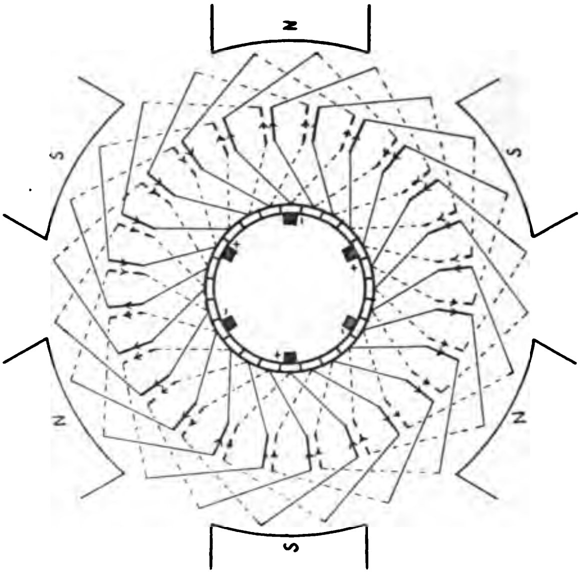


Fig. 15.—"Multiple Winding" for a 6 pole d.c. armature. The heavy radial lines with arrow heads represent the inductors. The dotted inductors are in reality placed beneath the solid ones shown beside them. The brushes are drawn inside the commutator to simplify the sketch.

the first one. The radial part of the line represents the inductor, which is shown dotted when at the bottom of a slot.

In small machines there are usually several turns per coil, the wire running around several times through the same two slots, with the ends connected to adjacent bars. If each coil in Fig. 15 contained 30 turns of No. 10 wire, of a total length of 80 ft., its resistance would be $80 \times .000997 = .08$ ohm. As there are 24 coils and 6 brushes, there are four coils

in series, with a resistance of $4 \times .08$ or .32 ohm. Current flows through the armature in 6 parallel paths, and hence the combined resistance $= .32 \div 6 = .053$ ohm.

The "current rating" of an armature is the number of amperes it can safely carry. It is evidently equal to the current which one wire can carry multiplied by the number of parallel branches in the armature.

If the safe current in each inductor of the armature of Fig. 15 is 15 amperes, the current rating is 6×15, or 90 amperes. There being 120 inductors in series, the generated voltage $= 120 \times .7$ if conditions of flux and speed are so arranged as to give .7 volt per inductor. The power generated $= 84 \times 90 = 7560$ watts. The armature copper loss $= 90 \times 90 \times .053 = 430$ watts, so that the output of the armature is 7130 watts.

The same armature might have a "series" or "wave" winding, which has only two parallel paths. With the same total number of inductors there would be 360 in series and a voltage three times as high as with the multiple winding. The current could, however, be only 30 amperes, and the power would be the same as before. The armature copper loss may be shown to be the same with both methods of winding.

There is resistance at the contact of the brushes and the commutator and in the material of the brushes. This causes an electrical loss which varies with the load carried.

Another important loss of power occurs in the field windings. In Fig. 14 suppose the field resistance to be 17 ohms and the current supplied to be 3 amperes. The power loss $= 3 \times 3 \times 17 = 153$ watts. If the rheostat is set at 4 ohms, there is a further loss there of 36 watts. Compound generators have copper losses in both shunt and series fields. Thus, if the "brush voltage" is 120 in Fig. 16, the shunt current 8 amperes, the load current 200 amperes and the series field resistance .01 ohms, the shunt loss =

Here is the million volt transformer used in the 1915 exposition. Note that the windings are placed around an iron core made of many thin sheets. All transformers have laminated cores to cut down the eddy current loss.

For the theory of transformers, refer to Chapter XIV, p. 94.

$120 \times 8 = 960$ watts and the series field loss $=$ $200 \times 200 \times .01 = 400$ watts.

Mechanical and Iron Losses.—In a d.c. generator there are three kinds of mechanical power losses and two different iron losses. The former include bearing friction, "windage" or air friction, and friction

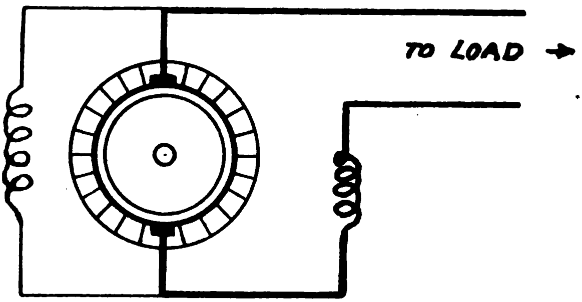


Fig. 16.—This compound wound generator has a loss of 960 watts in the shunt winding and 400 watts in the series coils.

between the stationary brushes and the moving commutator. The iron losses include those due to "hysteresis" and "eddy currents."

Armatures are influenced by the poles which surround them and become magnets themselves. As they rotate their magnetic condition must be continually changing, for each particle of iron is magnetized as it passes one pole and remagnetized in the opposite sense when it reaches the next. The particles oppose this change by what seems like internal friction, and the energy thus wasted (changed into heat) is the "hysteresis loss."

As the lines of force cut through the armature iron, currents of electricity are induced in it by exactly the same process as the currents in the armature wires. These "eddy currents" require the expenditure of energy and produce heat. To minimize the currents, which tend to flow parallel to the inductors, the armature is built of thin circular sheets, or "laminations" of iron. The oxide on the faces of the sheets forms an insulator which pre-

vents passage of the currents and thus reduces the eddy loss to a relatively small amount.

Armature Drop and Reaction.—In a separately excited machine (Fig. 14) or a shunt generator the brush voltage is lower when a load is carried than when the external circuit is open. One cause is the "armature drop," another is the "brush contact drop" and a third is the "armature reaction." It is to overcome these as well as "line drop" that the compound winding shown in Fig. 16 is used.

There is always a voltage drop in a conductor which carries current, and this is true even in an armature where voltage is being generated. Then in the armature of Fig. 15 with a resistance of .053 ohm, the drop is $90 \times .053 = 4.77$ volts when the machine produces 90 amperes. This would reduce the voltage from the generated pressure of 84 to 79.23 volts.

Due to the contact resistance between the commutator and brushes there will be a further drop of about one volt.

The armature inductors carrying current tend to make the armature a magnet with poles between the pole pieces of the generator. This results in lessening the total flux through the armature and makes other disturbances which lower the efficiency of the machine. The whole effect, known as "armature reaction," varies with the amount of current being drawn by the external circuit. Armature reaction is counteracted in various ways, such as shifting the brushes, building the generator with "interpoles," and putting "compensating windings" upon the pole faces.

IX

ELECTROLYSIS

The word "**Electrolysis**" is used to indicate the carrying of an electric current through a solution. It is found that absolutely pure water is an almost perfect insulator, but that the presence of an appreciable amount of any one of a number of substances makes the liquid a fairly good conductor. These soluble substances are called "electrolytes," and they

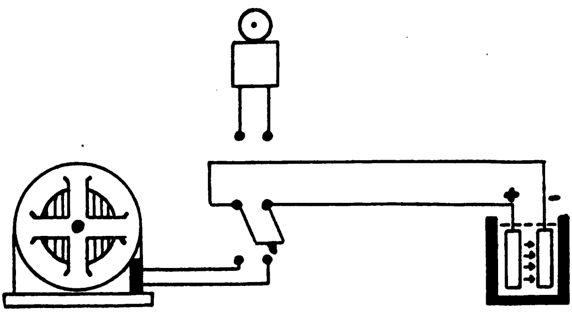


Fig. 17.—The d.c. generator sends current through the liquid from the "anode" (marked "+"), to the "cathode" ("—") when the switch is down. If the plates are lead and the electrolyte sulphuric acid, a battery is thus produced, capable of ringing the bell when the switch is up.

include acids, salts, and "bases" (or alkalis). Sugar is not an electrolyte.

The current is carried into and out of the solutions generally by metal "electrodes," the one where the current enters the liquid being called the positive or "anode," and the other the negative or "cathode." When the electrodes are far apart the current must pass through a long body of liquid, hence meeting

high resistance; when the electrodes are large the conducting body of liquid has a cross section, which lowers the resistance. Hence in all kinds of batteries, including storage cells ("accumulators"), the effort is made to have the electrodes as large and as near together as possible, for the current must flow between them and resistance causes loss of energy.

Chemical Effects.—When current flows through a solution, as in Fig. 17 when the switch is closed, it tends to separate and release at the electrodes the components of the electrolyte. For example, sulphuric acid is a union of hydrogen with the "sulphate

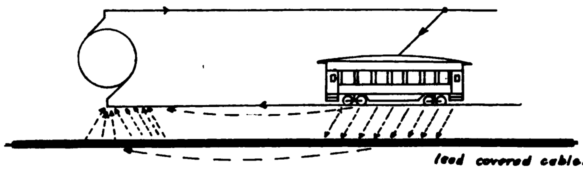


Fig. 18.—Current returns to the generator by the rails and through the earth. Part of the earth current is diverted to the lead covered cable and electrolysis destroys the sheath.

ion"; when current passes through dilute sulphuric acid the hydrogen is found to collect at the negative electrode and the sulphate is set free at the anode; being chemically active it immediately combines with water there, and liberates some oxygen. This gas may appear as bubbles upon the anode or it may unite chemically with the material of the anode; the hydrogen at the cathode may appear as bubbles or combine chemically with the material of that electrode.

In weak solutions the resistance is practically proportional to the amount of electrolyte present. This fact is utilized ingeniously by certain California engineers who determine by a single test the salinity of water in their steam boilers. A pair of electrodes fixed at a certain distance apart are immersed in a sample of the water and connected to a known voltage through a mil-ammeter. A single reading thus determines the resistance, from which is known the number of grains of salt in a gallon of water. Then

water which is too impure is blown out and fresh water substituted.

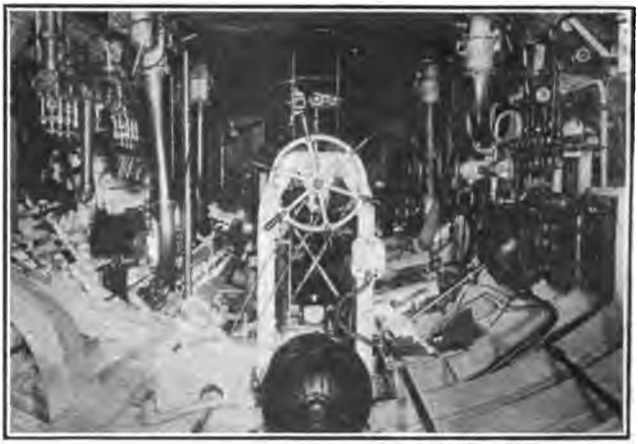
Moist earth carries current readily and makes trouble between electric railway companies and the people who own subterranean piping or metal cov-

Salinity tester used by the Pacific Gas & Electric Company. A bottle of boiler water is brought up around either pair of electrodes and the milammeter reads the current. The instrument is also calibrated to give a direct reading of the amount of salt present.

ered cables. Where a current leaves a metallic conductor (which is, then, the anode) the metal is dissolved and removed.

Storage Batteries.—If two lead plates are used as electrodes in dilute sulphuric acid and a direct current sent through the solution, as in Fig. 17, it is noticed that the arrangement soon becomes a battery, capable of sending electricity through a wire, though it was **not** a battery before the "charging

current" passed. This current changes the positive electrode to "lead peroxide" by giving oxygen to it, while the cathode remains lead. The chemical action of the acid upon the lead peroxide and the lead then causes an e.m.f. to be set up tending to send current out from the peroxide to the lead plate; the electrode by which the charging current entered the cell is the



"Do It Electrically" is the motto aboard this submarine. Large storage batteries are charged by gas engines when the boat is on the surface and they supply power for propulsion, lights, cooking, and many other purposes when the boat is submerged.

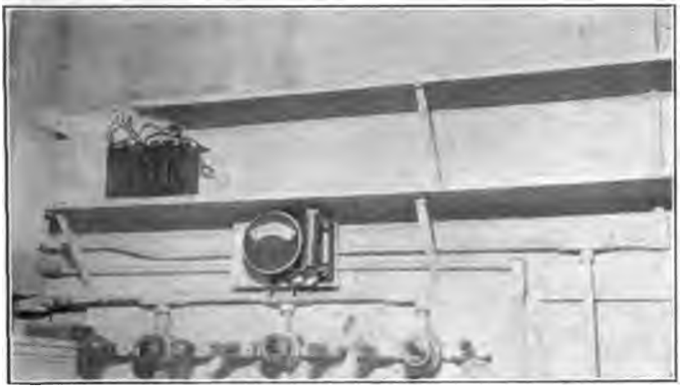
one by which current tends to go out when the cell is discharged by throwing the switch upward.

The chemical action during discharge is as follows: The hydrogen of the acid goes to the peroxide plate and takes off some of the oxygen, forming water, which dilutes the acid. The remaining oxygen of the peroxide plate is exchanged for sulphate ions, so that the plate becomes lead sulphate. Other sulphate ions go to the lead plate and combine with it, forming lead sulphate. So the sulphuric acid becomes weaker, losing hydrogen and sulphate ions; both plates become coated with lead sulphate.

Sending a charging current through again exactly reverses this action, taking sulphate ions off both plates and taking oxygen from the water to

make the positive plate into lead peroxide. The sulphuric acid is increased in strength.

These lead storage cells are very widely used. They are built commercially with the active materials (spongy lead and lead peroxide) in grooves or holes upon a lead backing. One cell generally contains several positive plates and several negative plates similarly interconnected, the two kinds being



This small storage battery does the work of two shelf-fuls of dry cells. It is charged for a few minutes each hour by means of a clock operated connection to a d.c. circuit.

interspaced and prevented from short-circuiting by wood and rubber separators. A number of these cells connected together form a "battery."

All cells of the same kind have equal voltage, the size and number of plates affecting only the resistance and the "capacity" of the cell—of course in a large cell there is more active material than in a small one, and it can give more ampere-hours before it is discharged.

The voltage of a battery equals the sum of the voltages of all the cells connected in series; if several cells are connected in parallel the pressure is no higher than that of one of them. The terminal voltage of a discharging battery is less than the generated voltage when current is flowing, just as in a generator. The current must pass through resist-

Fleet of electric trucks used in Portland, Oregon, by a department store. Each wagon is driven by a single motor connected to a nickel-iron storage battery. What is the voltage of such a battery containing 60 cells in series? If the resistance is .004 ohm per cell, what is the pressure required to charge this battery at the rate of 70 amperes? What is the terminal voltage when the output of the battery is 3.3 kw.? (Assume open circuit voltage = 1.3 per cell.)

ance in the cells themselves, and hence there is a voltage drop, depending on the current and the resistance. Toward the end of the discharge the resistance increases, causing the terminal voltage to diminish rapidly. The volts per cell, when discharging, drop from about 2.1 to 1.8.

The Edison Storage Cell.—In order to overcome some of the undesirable features of the lead battery, such as weight, acid fumes, and the necessity for constant and skilled supervision, Edison invented the nickel-iron storage cell which has become popular for electric automobiles and many other uses. The positive plate contains perforated tubes of nickel hydrate while the negative plate contains pockets of iron oxide. The electrolyte is a solution of caustic potash (chemically pure lye), which does not give off fumes. It is not changed in the processes of charging and discharging, which are chemically equivalent to transferring oxygen from one plate to the other.

The voltage of a single Edison cell is about 1.3, while the lead cell has about 2 volts. The pressure needed to charge an Edison cell is about 1.7 volts; to charge a lead cell, 2.3 volts. These figures are, of course, higher than the counter pressure generated in the cells, because the charging voltage has to overcome the voltage drop due to cell resistance as well as the voltage of the cell itself.

Primary Batteries.—Many batteries are in use in which the material of one plate is so changed and removed by the chemical reactions which cause current to flow that it cannot be restored by forcing current through the cell in the reverse direction. These are called "primary batteries" in distinction from accumulators which are sometimes called "secondary batteries." On account of its convenience and low resistance the "dry cell" is one type of primary battery very much used, and there are a number of different kinds of wet cell in use. To make a battery for experimental purposes one has only to put two pieces of metal of different kinds (or a piece of carbon and metal) into a solution of salt, an

acid or an alkali. A dime and a copper cent separated by a piece of moist blotter will produce enough current to make a click in a telephone receiver. The action of such a battery depends upon the **difference** in the chemical action upon the two electrodes. Since any electrolyte acts differently upon every kind of solid conductor, any two metals (or carbon and one metal) will serve for a battery with any electrolyte. The voltage is different for every combination, varying from a very small value up to about 2 volts. The "dry cell" which has sal ammoniac for its electrolyte (mixed with some filler to a sort of paste and sealed into the cell with wax) generates a pressure of 1.5 volts.

X

ELECTRIC MOTORS

Theory of Motor Action.—Oersted in 1819, laid the foundation of the modern electric motor when he discovered that current in a wire affected a nearby compass needle. He showed that the electricity tends to cause the movement of a magnet pole in a circle around the conductor. In Fig. 19, for instance, the current in wire A exerts a force upon the nearby north pole, trying to make it move upward, then to the right, then downward. A south pole would tend to circle the wire in the opposite direction.

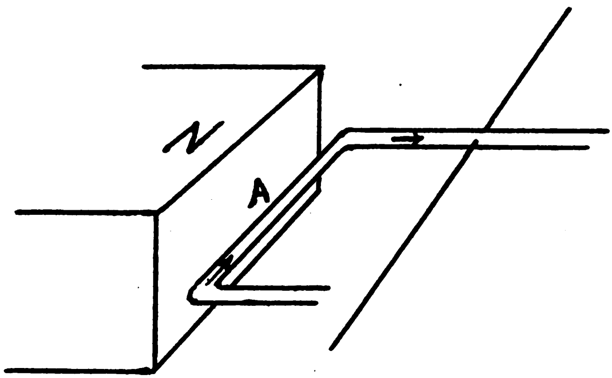


Fig. 19.—Current in Wire A tends to force the north pole upward. The reaction drives the wire itself downward.

Direct current motors are built with stationary poles, so that the wires themselves are made to move, just as a man trying to push a piano across a room may drive himself backward. Then in Fig. 19, wire A moves downward and the wire adjacent to a

south pole moves upward. One can always determine the direction by remembering the old **Right Hand Rule:** Grasp the wire with the thumb pointing along it in the direction of current flow; then a north pole will follow the fingers around the wire.

The armature of a motor is built of laminated iron with slots for the conductors. (See Fig. 20.) The

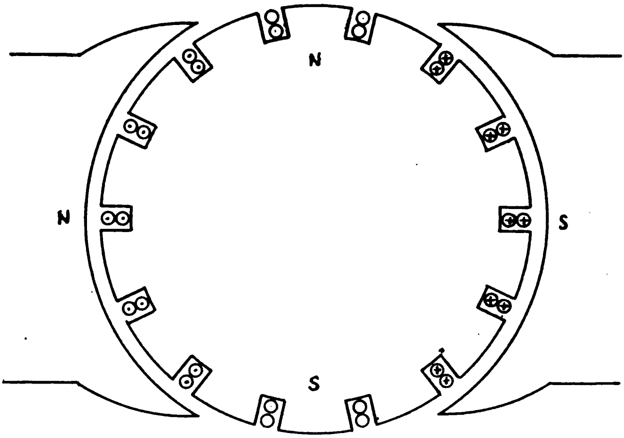


Fig. 20.—A motor armature. The currents in the wires may be thought of as producing poles in the armature iron which are attracted and repelled by the field poles.

commutator of a d.c. machine acts to keep the current always flowing in the same direction in the vicinity of any pole. In Fig. 20 it flows **"out"** (toward the observer) beside the north pole as indicated by the dots (arrow points); it flows **"in"** (into the paper) beside the south pole as shown by the (+) marks (arrow feathers).

If an armature such as that in Fig. 19 is supplied with an alternating current which reverses exactly "in step" with the rotation, so that current flows **"in"** along the other wire when that is beside the north pole, the machine will run and carry a load. This is the principle of the "synchronous motor." It follows that any electric generator will operate as a motor if supplied with current under proper conditions.

Another way to study the action of a motor is to think of the armature as an electromagnet. The coils in Fig. 20 tend to produce a north pole at the top of the armature and a south pole below. These are pulled and pushed by the field magnets according to the rule: Unlike poles attract and like poles repel each other. As the armature rotates, its poles continually shift through the metal and keep in their

Direct current motors of 15 hp. each drive these deck winches. What is the current input to one of the 116-volt motors when a load of 25000 lbs. is being hoisted 3 ft. per sec. if the overall efficiency of the machinery is 55%?

positions at the top and bottom, because the wires at the right are always carrying current **in** while those at the left carry it **out.**

Counter Electromotive Force. — In a rotating motor armature the wires are passing at high speed through lines of force. This must set up a voltage in these wires, whether they carry current or not, for an e.m.f. is always induced in a conductor being cut by lines of force. This voltage may either help or hinder the current flow; if it helps, there will be

more current and more magnetic force the faster the armature goes, which is contrary to reason and experience. We conclude that the induced e.m.f. opposes the current and the voltage driving it, and name it "counter e.m.f." or "back e.m.f."

The number of amperes through the armature depends, then, upon three things: the armature resistance, the applied voltage, and the back e.m.f. If we had a battery circuit of 2 ohms total resistance with 6 dry cells in series, the voltage would be $6 \times 1.5 = 9$ volts, and the current 4.5 amperes. If one of the cells were connected backward, however, the effective voltage would be $7.5 - 1.5$ or 6 volts, and the current 3 amperes. With two cells connected backward we should obtain 1.5 amperes. If three cells were opposing the rest there would be no current, for the net voltage would be zero.

If the counter voltage of a motor equaled the applied pressure, no current could flow, and no power would be drawn from the line. Hence the back e.m.f. is always less than the applied voltage, for it takes power to run a motor, even when unloaded. **The armature current = (applied volts — back e.m.f.) ÷ armature ohms.**

Motor Starting. — When an armature is stationary it cannot produce any counter e.m.f. If the full voltage were applied a very heavy current would flow, and for the protection of the windings it is customary to provide some sort of starting apparatus which limits the current to a safe value. Direct current shunt motors (which are wound the same as shunt generators) are started with a variable resistance in series with the armature, as shown in Fig. 21. By means of a sliding contact the resistance is lowered step by step as the motor gains speed, and it is all out when full speed is nearly reached.

Alternating current motors are often started by applying pressure less than the normal line voltage. "Compensators" which are "step down transformers" are connected to the line and supply current at

low voltage during the starting period. In other cases resistance is introduced into some of the motor circuits, while sometimes the connections of the coils are changed temporarily to produce effects equivalent to changing from parallel to series circuits.

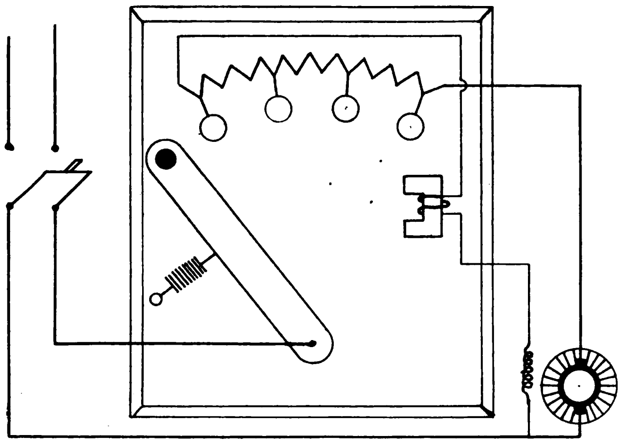
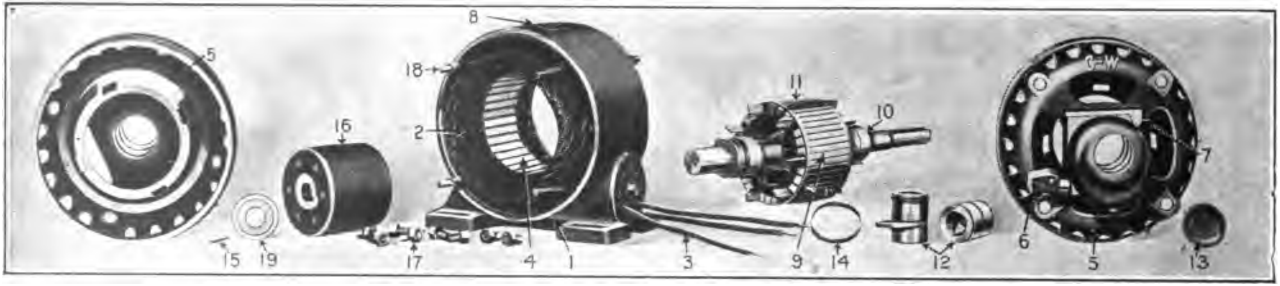


FIG. 21.—Starting box for d.c. shunt motor. To protect the armature winding, when it is producing little or no back electromotive force, the line current is sent through a series resistance which is decreased as the motor speeds up.

Alternating Current Motors.—Synchronous motors are used when it is desired to operate machinery at a speed exactly proportional to that of the generators supplying the current.

For driving the d.c. generators for electric railways and in other applications requiring large amounts of power it is usual to install synchronous motors in preference to other types, largely on account of their beneficial effect on the power factor of the transmission line.

Since they can not carry a load except when exactly in step with the alternations of the current supply, it is necessary to bring them up to speed by some special device. Sometimes the d.c. generator is connected to the direct current line and run as a motor during the starting period; in other installa-



Note the simplicity of this small induction motor. Part 4 is the stator with windings shown at 2 inserted in slots on the inner face. Part 9 is the rotor of the "squirrel cage" type with simple copper bars for inductors. The complete list of parts follows:

1. Stator Frame
2. Stator Winding
3. Motor Leads
4. Stator Core
5. End Shield
6. Oil Gauge
7. Oil-Hole Cover
8. Name Plate
9. Rotor Winding
10. Shaft
11. Rotor Core
12. Journal
13. Dust Cap
14. Oil Rings
15. Pulley Key
16. Pulley
17. Shield Nuts
18. Studs
19. Dust Cap Washers

tions the synchronous motor is started without load by means of a small a.c. motor of another kind.

For all ordinary applications, the "induction motor" is most widely used. The construction is simple, cheap and rugged, and operation and maintenance are easy and inexpensive. The typical motor

There are far less "kicks" in the mines since the electric motor displaced the time-honored mule locomotive. In some mines trolley lines are used; in others the motors are driven by storage batteries carried by the locomotives themselves (as in this illustration).

of this type has no sliding contacts and only the simplest elements of a winding upon the revolving part or "rotor."

Alternating currents in coils wound about portions of the iron "stator" (stationary part) of an induction motor produce magnetic poles which are north when the current flows one way and south when it reverses. Other poles of opposite polarity are produced between these by coils wound in the opposite direction. The result is that north poles appear at several points around the stator and shortly after (when the current has reversed) they appear in different places. By the use of two or more alternating currents which reverse at different times there is produced a smooth progression of the poles

around the inside of the stator, and this is known as the "revolving field."

Just as in the alternating generator, the wires near the poles of a revolving field are cut by the moving lines of force and have e.m.f. induced in them. Thus the conductors of the rotor, which are short circuited upon each other, carry heavy induced currents, but no electrical contact with the supply circuit is needed. The reaction between these induced currents and the magnet poles of the stator causes the rotor to turn. As it gains speed it almost catches up with the revolving field but it never runs quite as fast. If it did, there would be no more induction of e.m.f. on the rotor, for each wire would keep beside some pole and there could be no cutting of the inductors by lines of force. The difference between the speeds of the rotor and the revolving field is known as the "slip," and this varies whenever the load is changed.

XI

MOTOR CHARACTERISTICS

Direct Current Motors.—For operation upon d.c. circuits motors are built of three different types. They are known as series, shunt and compound motors, the names referring to the connection between the armature and the field winding, as in the

A Westinghouse motor-generator set run by direct current and producing alternating current. This last is raised to high voltage by means of transformers and then "rectified" for use in precipitating dust in flue gases.

case of d.c. generators. The magnet coils in a series motor consist of a few turns of large wire carrying the whole current of the machine. A shunt motor has field windings of small wire and many turns, connected in multiple or shunt with the armature. Both series and shunt coils are put upon the field of a compound motor.

The **"torque"** or turning effort of a motor depends upon the strength of the magnetic field and hence is proportional to the field current except for the disturbing effects of saturation and armature reaction. Therefore, decreasing the field current to half value cuts the torque approximately in two.

This direct current G-E fan runs at 1500 r.p.m. When the fan blades are removed, the motor runs at about 3500 r.p.m. Is the field shunt, series, or compound wound?

This is on the assumption that the current in the armature remains constant, for the torque is directly proportional also to armature amperes. Then in a series motor, where the same current flows through armature and field, triple current would give nine times the torque were it not for the disturbing factors mentioned above. (On test a certain 500-volt machine was found to give with 60 amperes five times as great a torque as with 20.)

Series motors are used for electric railways, hoists, cranes, etc. When a street car starts up-hill from the level the motors at once lose speed and the counter e.m.f. decreases. More current is thus permitted to flow and this raises the torque of the motors sufficiently to carry the increased load. This flexibility in regard to torque and speed is what makes the series d.c. motor the most convenient for all such applications as hoisting and traction where heavy and variable loads must be frequently started and stopped. It is necessary to keep a series motor coupled to its load, however, and to control it care-

fully, for if the load is removed the speed will run very high, possibly ruining the armature by centrifugal action.

Shunt Motors.—When a shunt motor is operated without a load it does not run faster than a certain speed, behaving like a steam engine with a governor, in contrast to the series motor which acts like an ungoverned automobile engine. At the "no load speed" of a shunt motor it develops a back e.m.f. almost equal to the applied voltage, so that only a small current can flow. A slight increase in the speed would raise the back e.m.f. so high that no current could enter the armature and the machine could take no power from the line.

When a shunt motor is required to drive a load it must absorb more watts than when running idle. Suppose 100 volts applied to the armature and the back e.m.f. at no load equals 99. The net voltage driving current through the armature is, then, 1 volt, and the current will be 10 amperes if the resistance is 0.1 ohm. If a load is then applied which requires an input of 4 kw., the current must rise to $4000 \div 100$, or 40 amperes, which means that the net voltage must be $40 \times 0.1 = 4$. The back e.m.f. must drop to 96 volts, which means that the speed must drop to 96/99 of the no load speed. At full load a shunt motor runs about 5% slower than at no load.

It is often desirable to run a shunt motor at other than normal speed. In a machine shop, for instance, a motor driven lathe should have several available speeds suitable for different jobs. There are four ways of accomplishing this: (1) By installing a multivoltage system; (2) by rheostat control of armature current; (3) by changing the field flux mechanically; (4) by rheostat control of the field current.

With two or more generators one can apply to the motor armature different voltages and obtain speeds in proportion. The field strength may be kept constant by using always the same voltage for ex-

citation. A similar effect may be obtained by putting a rheostat in series with the armature and thus lowering the applied e.m.f. by means of the voltage drop. This method is wasteful of power, while the first is expensive and complicated.

Weakening the field of a shunt motor by moving the poles and armature farther apart or by putting

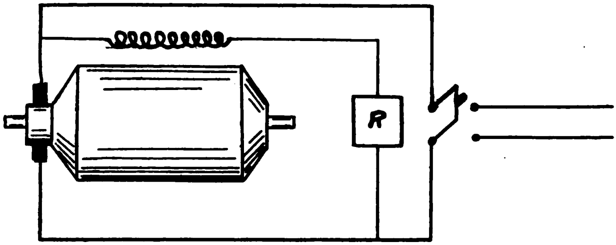


Fig. 22.—Cutting down the field current in this shunt motor by means of the rheostat causes the armature to run faster. It must do this to keep the counter electromotive force nearly equal to the voltage of the line.

resistance into the exciting circuit changes the speed (see Fig. 22). Suppose the unloaded 100-volt motor considered above had its field weakened 7% — what alteration in speed would occur? The back e.m.f. would instantly fall to about 92 volts and a large current would flow ($8 \div 0.1 = 80$ amperes). This would produce a strong torque and speed up the armature until the back e.m.f. reached approximately its former value. Weakening the field **increases** the speed.

Compound Wound Motors.—Some motors have a series winding in addition to the shunt coils on the field poles. Imagine current supplied to a compound generator, entering at the positive (+) terminal (from which the current was sent out when the machine was generating). Would the series field help or oppose the shunt field, and which way would the armature rotate? The current would flow in the old direction through the shunt coil (from the + to the — brush), but in the reverse direction through the series coil. Hence the field will be weakened by the series coil. The armature will rotate in the old

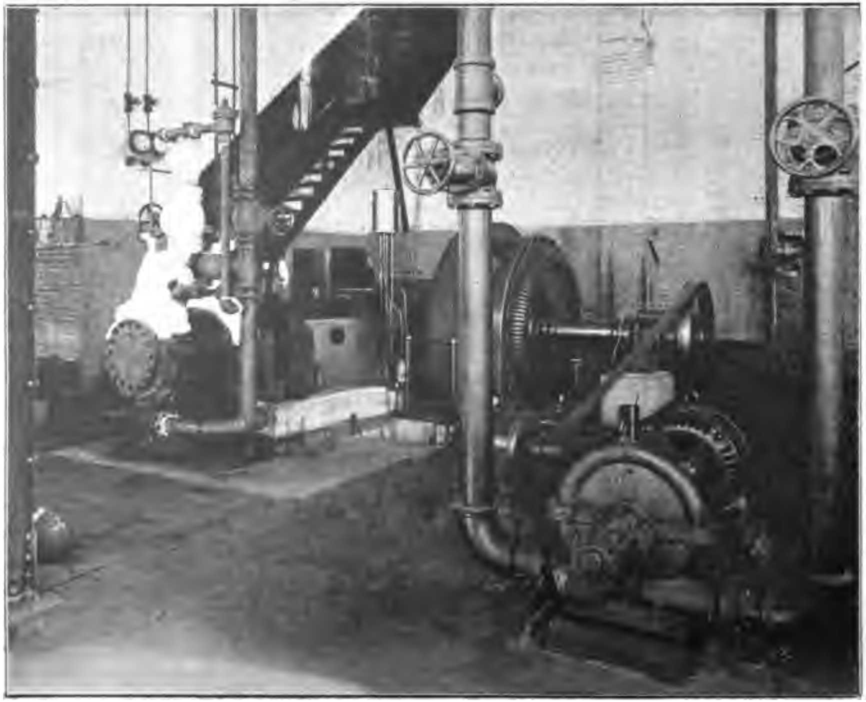
direction, for it must produce an induced e.m.f. opposing current, and hence directed out at the + brush. When a load is put upon this motor the increased current in the series coil tends to weaken the field and hence to increase the speed. Thus a compound motor can be arranged to have a constant speed with varying load.

A "cumulative compound winding" is produced when the series coil is connected the opposite way, so as to assist the shunt coil. Such a winding gives a strong torque at starting, due to the heavy series current and the strong field it produces. An increase of load in such a machine causes the speed to drop more than with a simple shunt winding, as the increase of current strengthens the field. Such a characteristic is desired for such machines as punch presses, shears, etc. These motors with various degrees of compounding are used also for elevators, rolling mill machinery, etc.

Alternating Current Motors. — A synchronous motor runs at a constant speed which is determined by the number of poles and the frequency with which the supply current reverses its direction. Adding or taking off the load changes the number of amperes, and varying the field strength changes the "phase relation" of the supply current, but the motor runs at constant speed unless the load is heavy enough to make it "fall out of step" and come to a standstill.

Induction motors without load run at nearly synchronous speed. This can be calculated from the number of poles and the frequency of the supply circuit. For "60 cycle current" the revolutions per second = 60 ÷ no. of pairs of poles. Thus a 6 pole motor makes 20 revolutions per second or 1200 r.p.m. unloaded. The 50 cycle current used in Southern California drives a 4 pole synchronous motor at 1500 r.p.m.

As the load on an induction motor is increased its speed decreases, the "slip" varying from practically zero to 5% or more. Some motors, specially



Refrigeration plant run by electric drive. In Southern California this large motor runs at 200 r.p.m. on 50-cycle current and drives an ammonia compressor.

How many poles on the revolving field of the motor?

built with high resistance rotors, have a slip of 10 or 15%. Such machines are used for driving the rolls in steel mills and similar work where the load is heavy and intermittent. With a punch press, for instance, such a motor can speed up and deliver energy to a heavy flywheel during the interval between operations, and then slow down to give the

An induction motor driving a wood saw. This small machine runs at 1200 r.p.m. when unloaded, and is rated at 5 hp. Calculate the number of poles and the frequency of the alternating current supply.

flywheel a chance to do much of the work of driving the punch. A constant speed motor would be of very little value for such applications for it would be very heavily overloaded part of the time and idle for the remainder. The cumulative compound d.c. motor and the induction motor with large slip are much used with flywheels for this class of work.

XII

ELECTRIC METERS

Direct Current Instruments. — Practically all electrical meters operate by reason of the production of magnetic fields by electric currents. The earliest indicating instrument was merely a single wire held above a compass needle. A flow of electricity in the wire caused the needle to turn through an angle dependent upon the strength of the current. Running the wire below the needle doubled the turning moment and it was a short step to the simple galvanometer which consisted of a compass mounted in a coil of wire with the needle perpendicular to the axis of the coil.

There are serious disadvantages connected with the use of the "moving needle" type of instrument, and these are eliminated in the "moving coil" and "magnetic vane" meters now commonly used. The moving coil meter of the D'Arsonval type has a coil like the armature winding of a motor, and this is placed in a magnetic field. When current (which is led into and out of the coil through spiral springs around the shaft) flows through the winding, the armature turns for the same reason that a motor revolves, but the springs restrain the motion so that the attached pointer moves only a limited distance. The torque depends upon the armature current, and hence the pointer indicates upon its scale a reading proportional to the current. (See Fig. 6, p. 23.)

In instruments of this type every motion of the coil causes the metal bobbin upon which it is wound to move through a strong magnetic field. This in-

duces eddy currents in the metal, the effect of which is to slow the motion and prevent vibration of the coil after the needle reaches the point where the reading should be made. Such instruments are called "dead beat." Other meters do not depend upon eddy current "damping" but contain air chambers in which move vanes which stop vibration by air friction.

Edgewise Ammeter. This instrument is used on station switchboards for metering direct current.

Light moving coils with delicate springs can not carry heavy currents, and ammeters of this type usually contain "shunts" which carry a definite fraction of the total amperes in multiple with the coil. The scale of the instrument is marked or "calibrated" to indicate the total current flowing in the coil and shunt.

A "milliammeter" or "mil-ammeter" is adapted to measure small currents and marked in thousandths of an ampere. Suppose the coil of such an instrument to have a resistance of 9 ohms and imagine a coil of 991 ohms connected in series with it inside the case. There would be a total of 1000 ohms between terminals, and if a pressure of 30 volts were applied, the current flow would be only 0.030 amperes or 30 mil-amperes. The scale reading would be 30, exactly equal to the voltage. A voltmeter, then, is simply a very sensitive galvanometer or ammeter with large resistance. Such an instrument is calibrated by connecting it in multiple with a stand-

ard voltmeter and altering the voltage by suitable steps.

If it is desired to use a 150-volt voltmeter on a 1200-volt circuit it is necessary to put more resistance in series with it. Manufacturers supply "multipliers" which are simply resistance coils to be used in this way. The meter reading must be multiplied by the appropriate factor to get the pressure.

Multiplier to use in connection with a voltmeter or wattmeter. What resistance should it have to make a 9000-ohm voltmeter read 140 on a 560-volt circuit? What would the multiplier be called?

Electrodynamometer Instruments.—Many moving coil ammeters and voltmeters have magnetic fields produced either by permanent magnets or by electro-magnets excited by a steady current. The "electro-dynamometer" ammeter or voltmeter, however, has a field coil connected in series with the moving coil, so that the torque depends upon the square of the current. The instruments contain no iron, and the reaction between the coils is spoken of as electro-dynamic, rather than electro-magnetic. The reading scale of such an instrument is not regular or uniform but the marks are much wider apart at some places than others.

The power in a d.c. circuit equals the product of volts times amperes, and it can be conveniently metered by an electro-dynamometer instrument. The moving coil (with high resistance) is connected across the line and takes a current proportional to the voltage. The stationary coil is put in series with the load and so carries the load current. The torque

developed is proportional to the product of pressure and current and hence the scale may be calibrated in watts or kilowatts. The divisions may be very nearly uniform. Such a wattmeter may be used for high voltages by connecting a multiplier in series with the voltage coil, and for large currents with the help of shunts like ammeter shunts.

General Electric Wattmeter. Why are there more terminals than on a voltmeter? Is this instrument built for a switchboard or for occasional use? For connections, see Fig. 5—page 15.

Metering Alternating Currents.—If the current is reversed in a moving needle instrument or in one having a moving coil and a permanent magnet, the pointer will be seen to deflect in the opposite direction. Such meters can not, then, be used on alternating current circuits. Electro-dynamometer instruments, however, operate perfectly with alternating current, for the field of the stationary coil reverses as often as the current in the moving coil, thus producing torque always in the same direction. Hence electrodynamometers are often used for a.c. circuits, as ammeters, voltmeters and wattmeters. They may be calibrated with direct current and used on either kind of circuit.

Various other meters have been developed for use with both direct and alternating current. The "electrostatic voltmeter" consists of moving and stationary vanes which are charged with static electricity by connecting to the opposite sides of a high

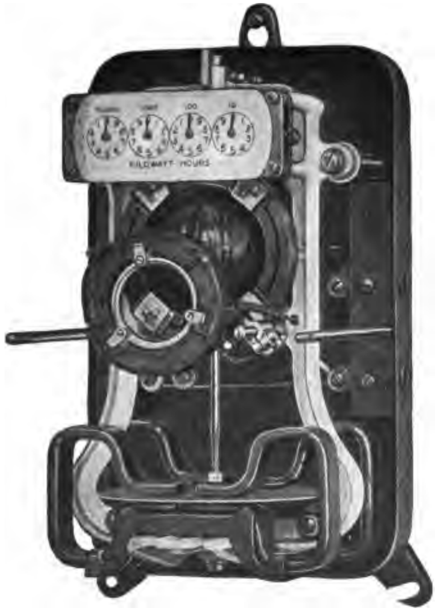
potential circuit. The vanes are drawn toward each other, moving a pointer against the restraint of a spring. A fountain pen rubbed upon a coat sleeve will attract bits of paper by a similar electrostatic action.

A device used for both ammeters and voltmeters is the "hot wire." Current through a piece of resistance wire heats it, causing expansion which permits a spring to pull a pointer across a scale. Another scheme is to use for a voltmeter or ammeter a stationary coil surrounding two light parallel iron rods, one of which is fixed in position. The other is attached to the pointer and can move around the inside of the coil, always keeping parallel to the fixed rod. Both rods are magnetized when current flows, and the repulsion of like poles causes one to move away from the other. Still another device consists of a soft iron plunger which is sucked into a coil when current flows around it, the plunger being supported by the spindle which carries the pointer. Pocket instruments for testing dry cells are of this type. All these meters will work with more or less accuracy upon alternating as well as direct current circuits, for, obviously, reversing the current does not reverse the effect upon the pointer.

Many alternating current voltmeters, ammeters and wattmeters are of the "induction type." In these a rotating field is produced, as in the induction motor, and this induces in the rotor short circuit currents which tend to turn it on its axis. A restraining spring and a pointer complete the moving element. Such instruments can, of course, only be used on a.c. circuits. An induction wattmeter has certain coils connected across the line and others in series with the load; ammeters and voltmeters have all their coils in series.

Watthour Meters.—Instruments for measuring energy consumption are often mistakenly called "wattmeters." A watthour meter is a small electric motor so constructed as to use up very little energy and yet to run at a speed proportional at all

times to the power taken by the electrical load on the line. By means of a revolution counter a record is made on the dial of the number of revolutions of the armature, thus accounting for the kw-hr.



Interior of a direct current watthour meter. Note the four permanent horseshoe magnets and the retarding disc between their poles.

that have passed the meter. Many d.c. watt-hour meters have commutators and brushes, the armatures being of high resistance and connected across the line so as to carry current proportional to line voltage. The field is then connected in series with the load. Such meters have no iron at all in the magnetic circuit, which means that the flux and torque are proportional to the voltage and current and no complications are caused by variations in permeability, etc.

Reversing the current in both the armature and series coils of such a meter gives torque in the previous direction, and hence it may be used on a.c. circuits. For several reasons, however, watthour

meters of the induction type are generally preferred for such service. These are simply induction motors, lacking commutator and brushes, and thus having no moving contacts.

It is necessary in all watthour meters to restrain the motion of the armature or else even a light load would cause rapid rotation and high readings on the

Testing meters taken from residences in Fresno, California. Are these wattmeters or energy meters?

dials. Usually a disc of aluminum is attached to the armature shaft and arranged to rotate close to the poles of strong permanent magnets. Eddy currents are set up which hold back the disc with a force proportional to the speed, and the result is that the speed is made proportional to the driving torque of the armature. In induction watthour meters the retarding disc serves also as armature, the revolving field setting up in one part of it eddy currents which cause it to move, and the stationary magnets setting up in another place currents which retard it.

Curve Tracing Meters.—Many meters are in service which make graphical records or charts. The curve drawn by a recording voltmeter, for instance, tells the voltage at every instant during a

period of twenty-four hours. New sheets are inserted daily and thus continuous record is kept, which at any future time may be called upon for information regarding pressure fluctuations, short circuits, etc. Station operators who fall asleep on the "graveyard watch" sometimes are thus betrayed by a record of voltage too high or too low during half an hour.

Such an instrument includes a meter with a pen mounted on its pointer, and a clock for moving a piece of paper uniformly past the point of the pen. The mechanism of the meter may be similar to that of an ordinary electrodynamic voltmeter or wattmeter, but with sufficient turns of wire to give strong forces to overcome pen friction, etc. Other recording instruments make use of relays so that the pen is moved by electromagnets operating when the metering mechanism closes certain contacts.

XIII

LAMPS AND ILLUMINATION

Commercial and home portrait photographers use gas filled Mazdas in deep reflectors to illuminate their subjects.

ALL sorts of lamps are used for producing artificial light, but in this country the incandescent lamp is used to a greater extent than all others combined. Until recent years the carbon filament lamp of this type was the standard, but the superior economy of metallic filaments has caused the carbon lamp to be practically displaced by the tungsten lamp. The latter gives approximately three times as much light as the former for the same power consumption.

In lamps of medium and large size it is found that the efficiency is increased by filling the bulb with an inert gas, such as nitrogen. The ordinary tungsten lamp has the air removed, the filament being allowed to glow in an almost perfect vacuum. The gas permits the filament to be heated to a higher temperature. This means that a larger proportion of the energy expended in heating the wire is radiated off in light waves. For instance, the vacuum lamp in the 100-watt size gives only 80% as much light as the gas filled 100-watt lamp.

Lamps carrying large currents have better efficiencies than those of smaller amperage. The 200-watt 220-volt Mazda has the same efficiency as the 100-watt 110-volt lamp, and only 86% as high efficiency as the 200-watt 110-volt lamp.

Local lighting gives the largest proportion of the total light of the lamps at the point of use

Candle Power and Foot Candle.—If an incandescent lamp, hung in the usual position with base upward, gives off in a horizontal direction as much light as a standard candle, it may be called a "one

Western power plant illuminated by flood lighting. This system of outdoor illumination of buildings first came into extensive use in the Panama-Pacific Exposition of 1915.

candle power" (one c.p.) lamp. More accurately we say that its "horizontal candle power" is one. This point must be emphasized, for the amount of light sent in other directions is not the same.

If a lamp is located at the center of a globe or sphere, it sends light to nearly every point on the inner surface, but different amounts to different places. The average candle power in all directions is called the "mean spherical candle power," and it is usually considerably less than the "horizontal candle power." Ordinary lamps have a mean spherical c.p. equal to about .8 of the horizontal c.p.

If a very concentrated one c.p. light is one foot from a wall, the illumination at the point on the wall nearest is one "foot candle." Every other part of the surface is less brightly lighted, since it is more than a foot away. However, if the wall were warped so that a considerable part of it was exactly one foot from the light, the illumination would be one foot candle all over that part. A spot on a wall one foot from a lamp of 20 horizontal c.p. would be illuminated with an intensity of 20 foot candles.

For various purposes different intensities of illumination are required. In the operating room of a hospital the illumination on the "working plane" (the plane level with the table top) should be 12 or more foot candles; in a dining room 2 foot candles would be satisfactory. Following are the suggestions of various illuminating engineers for a few cases:

Auditorium	1 to 3	Lavatory	2 to 6
Cigar Store	4 to 6	Library (tables)	3 to 4
Coil Winding	4 to 12	Office	4 to 10
Department Store	4 to 10	Outdoor Construction	.5 to 2
Drafting Room	7 to 12	Proof Reading	4 to 12
Drug Store	3 to 8	Residence-Cellar	0.6
Elevator	1 to 3	Residence-Kitchen	2.0
Engine Room	3 to 9	Residence-Parlor	1.5
Garage	3 to 9	Shoe Store	3 to 5
Grocery	3 to 6	Stairs and Halls	.5 to 2
Laundry	3 to 9	Telephone Exchange	3 to 9

Reflectors.—Reflectors or shades are used with nearly all incandescent lamps, though they absorb much of the light and therefore are far less than

100% efficient. A surface of porcelain over steel, which is much used in shop and factory reflectors, absorbs about 35% of the light that falls upon it.

There are two good reasons for the use of bell-shaped reflectors for interior lighting: (1) they put

Indirect lighting in the new and beautiful California Theater, San Francisco. Note the individual reflector for each lamp.

the greater part of the light where it is wanted and (2) they protect the eyes by making it impossible to see the glaring filament unless one looks in an unusual direction. An ordinary bare lamp throws

very little light downward (past the tip), and so is very inefficient if hung vertically over the work to be lighted. Furthermore the intense light which enters the eye of a person who has a bare lamp within his angle of vision is not only annoying but also painful and injurious.

Indirect Lighting.—In some cases the reflectors are turned upside down and arranged to throw all the light toward the ceiling. Then the useful light in the room is only that which is reflected downward from the ceiling or from special white surfaces placed above the lamps. This is known as "indirect" or "totally indirect" lighting. Note that the reflectors are completely opaque.

The method is very considerably adopted because it gives freedom from eye strain. It requires more wattage than any other system, and tends to decrease rapidly in efficiency on account of the collection of dust. Some objection is made to indirect lighting on the ground that shadows are largely eliminated, which makes it difficult to see the details clearly. It has been claimed, however, that with the same eye fatigue from two to five times as much drafting and similar work can be done under indirect lighting as with any other artificial light.

A modified method, known as "semi-indirect" lighting, is widely used. A translucent reflector is put under the lamp, permitting a portion of the light to come through as well as reflecting much light to the ceiling. This is fairly efficient and has many advantages, but is open to some of the objections to both the ordinary and the indirect systems.

If reflectors were perfectly efficient and walls and ceilings reflected all the light that reached them, absorbing none, the total light flux from the lamps would reach the working plane. In most installations it receives only from 20 to 60% of the light emitted by the lamps.

By multiplying the required foot candle intensity in any room by the area of the working plane

(which equals the floor area) we obtain a measure of the useful light necessary. This figure has to be multiplied by a factor of from 1.7 to 5 or more to find the total light the lamps must give. Below are

Warehouse lighted by large lamps (300-watt gas filled) at a total expenditure of .15 watt per sq. ft. What is the size of the squares into which the ceiling is divided by the lighting fixtures? What part of the light is wasted if the illumination averages one foot candle at the working plane

listed some approximate factors for small rooms with light ceilings:

Reflector	Light Walls	Dark Walls
Prismatic glass bowl	2.7	3.0
Steel bowl (deep)	2.6	3.0
Light opal glass	3.4	3.7
Totally indirect	5.0	6.2
Semi-indirect	4.3	5.3

A 25-watt Mazda lamp has a mean spherical candle power of 17.7. If it were surrounded by a spherical shell one foot in radius, the inner surface of the shell, being one foot from the lamp, would receive an average illumination of 17.7 foot candles. As there are 12.57 sq. ft. of surface, the total light

emitted by the lamp may be figured as $17.7 \times 12.57 = 223$ units. Similarly a 500-watt gas filled lamp (mean spherical c.p. $= 694$) produces a flux of $694 \times 12.57 = 8720$.

Such numbers are found in the following table for the most common lamps:

Ordinary Tungsten			Gas Filled (Mazda C)		
Watts	Spherical c.p.	Total light	Watts	Spherical c.p.	Total light
15	10.0	125	75	69	865
25	17.7	223	100	100	1257
40	29.4	369	150	163	2050
60	45.8	575	200	232	2920
100	79.5	997	300	385	4830

What size lamp should be used in the six indirect lighting fixtures in a reading room 23 x 30 ft. with light ceiling and dark walls? Take foot candles $= 3.5$ by the first list; the area $= 690$ sq. ft., hence the useful light $= 3.5 \times 690 = 2415$ units. The total light $= 6.2$ times this, or 15,000 units, which requires 2500 units of light from each of the six fixtures. Hence, select 200-watt gas filled lamps.

Similar calculations are made for many effective lighting installations, but the design is not generally as simple as this example might suggest. Considerations of art, utility, and the plans of the owners and architect complicate the situation, so that much study and experience are required to develop power to plan satisfactory lighting systems.

XIV

INDUCTION—TRANSFORMERS—INTERPOLES

Induction Coils.—If a coil carrying current is thrust into another coil, an electromotive force will be induced in the latter, due to the cutting of the

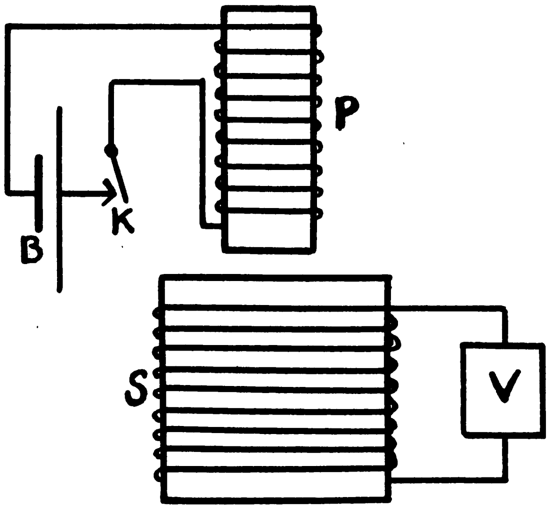


Fig. 23.—The Induction Coil consists of two independent coils with the same core. Varying current in the Primary (P) induces e.m.f. in the secondary (S).

wires of the second by the lines of force. If the "primary coil" (P, Fig. 23) has an iron core, it will, of course, have a greater flux than otherwise, and so produce more "interlinkages" of lines of force with the turns of wire of the secondary, S. The voltage set up is proportional to the number of inter-

linkages (number of lines $\times$ number of secondary turns) and the quickness with which they are produced — one volt if the rate is 100,000,000 per second. Leaving the primary standing within the secondary induces no voltage, and the needle of the voltmeter stays at zero. But breaking the primary circuit at K produces the same effect as withdrawing coil P, destroying the interlinkages and moving the voltmeter pointer in the negative direction. Closing K sets up the linkages and gives a positive indication on V. Thus we obtain an alternating current in S by starting and stopping the primary direct current, but we get no effect with a steady primary current when the coils are stationary.

If we replace K by a telephone transmitter, any sound near it will cause motion of the diaphragm, with consequent variation in the resistance of the instrument. When the primary current rises, it increases the flux and sends current in one direction through the secondary circuit; when it decreases it produces secondary current in the opposite direction. The apparatus (P and S) thus used constitutes the "induction coil" found in every telephone circuit. The ordinary induction coil, used to shock people for the betterment of their health or to produce sparks for ignition and wireless telegraphy, consists of the primary and secondary coils and some apparatus for suddenly opening and closing the circuit at K.

Transformers. — When alternating current is supplied to the primary coil, the apparatus becomes a "transformer." The flux produced by the primary and linking with the secondary is directed first one way and then the other as the supply current flows forward and backward. Every time the flux comes to a maximum and commences to decrease, the secondary voltage stops and reverses. Thus is obtained an alternating e.m.f. of the same "frequency" (number of cycles per second) as the primary current.

The ratio of the induced voltage to the pressure applied to the transformer is almost exactly the same as the ratio of secondary to primary turns. Under

operating conditions the secondary voltage is a little lower than is indicated by this relation, on account of drop due to resistance and the "leakage" of part of the flux (some lines are produced by one coil and fail to link with the other).

Iron cores are used in induction coils and transformers, the latter usually having a complete iron path for the flux, while the former have "open cores" which are merely straight bars of iron. Of course the laminated construction must be used for all cores

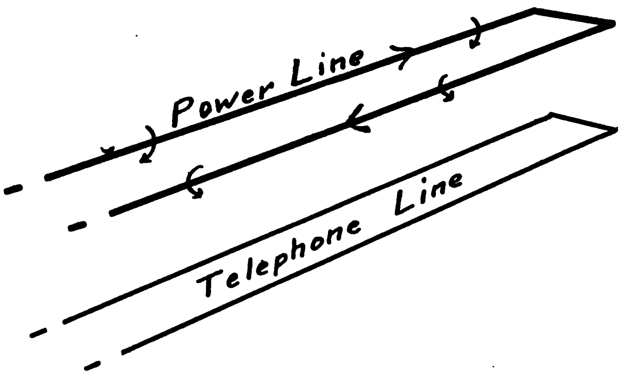


Fig. 24.—At one instant the current and magnetic lines of the power circuit are as indicated. When they reverse, the lines which reach the telephone wires induce a voltage there.

carrying an alternating flux, to prevent undue losses by eddy currents. (See illustration of transformer construction, p. 52.)

Whether or not iron cores are used, the changing flux due to varying current in one circuit will set up an alternating e.m.f. in any other circuit with which the lines become linked. Thus the apparatus of Fig. 23 will give evidence of a small effect on V, even if the coils are separated as shown and contain only an air core.

This "mutual induction" is often troublesome. Coils near together on a telephone switchboard used to affect one another and produce "cross talk" until each coil was surrounded by an iron case which kept the flux from straying. In a telephone line near an

a.c. power circuit (Fig. 24) alternating currents are induced by the lines of force which link with the telephone wires. It is to overcome mutual induction that the conductors of power lines and telephone systems are crossed over each other or "transposed" at intervals.

Self Induction.—Flux set up by a coil links first of all with the wires of that coil, and this interlinking produces inductive effects similar in principle to

In this induction motor the alternating current in the primary winding is choked down to a safe value by self-inductance. Short circuited currents are induced in the rotor by what resembles transformer action.

those of mutual induction. When K is opened (Fig. 23) a spark appears there, more evident if there is an iron core in the coil. A voltage is induced by the change of linkages, and this may be far higher than the battery voltage. Indeed, one may obtain a very perceptible shock with a small electromagnet (such as that in an electric door bell) and a single dry cell.

The voltage induced by the cutting down of battery current and consequent reduction of linkages is, naturally, so directed as to oppose this diminution of current. Thus the current is kept flowing through the increasing resistance of the opening key, crossing the air gap in a spark or arc. The faster the gap is opened the greater the voltage induced.

Low speed gas engines sometimes have the "make and break" spark for ignition. A pair of contacts inside the cylinder are caused to touch, and

The pitting in this generator shaft was caused by currents induced in the metal by a varying magnetic flux. The current flowed through the shaft and frame, crossing the oil film at two bearings. Until the bearings were insulated there was a very severe loss of power here.

current flows from a battery through a coil of high "self inductance" (having an iron core and many turns of wire). When the circuit is suddenly broken, a spark jumps across the break and ignites the explosive charge. A similar device is used for lighting gas lamps and stoves.

When an electromotive force is applied to a circuit containing self induction, the current grows but slowly, for the increasing interlinkages induce a counter voltage. An alternating e.m.f. sends through an inductive coil a current which is small compared with what it could send through an equal non-inductive resistance, because the voltage begins to decrease before the current has time to rise much. Furthermore, the voltage falls to zero and reverses some time before the current does. Such a current is said to be "lagging," and in these cases the power factor is less than 100%. Small induction motors often take current lagging so much that the power factor is 80% or less.

Commutation.—Fig. 25 represents a four pole d.c. generator at the instant when each of the brushes touches two commutator bars. The coil including inductors numbered 1 and 6 is short circuited by brush A at this time. Just before the brush touched the left hand bar, current was flowing in inductor No. 1 the same way as in Nos. 2 and 3; an instant later, when brush A no longer touches the right hand bar, current must flow the opposite way in No. 1, for it will then be under the south pole. The current in the coil must stop and reverse in the time it takes a commutator segment to pass across the face of one brush—possibly 1/500 sec. in an ordinary machine.

Self induction keeps the current flowing in the coil after it is short circuited, thus producing heat and making trouble at the face of the brush. To remedy this an "interpole" (IP, Fig. 25) may be placed between the main poles. The flux it produces must be enough to overcome the magnetizing effect of armature reaction and in addition induce in the

short circuited coil a voltage opposing the e.m.f. of self induction and assisting the starting of current in the new direction. The interpole winding is connected in series with the armature and hence its strength is proportional to the armature current.

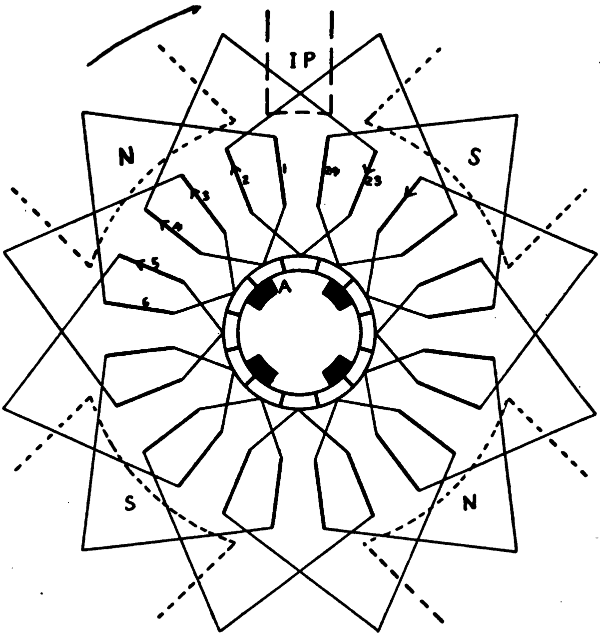


Fig. 25.—Four pole d.c. generator armature. The heavy radial lines numbered 1, 2, 3, etc., represent the inductors. To avoid confusion the brushes are drawn inside the commutator.

The interpole shown should have south polarity, to prepare the inductors for the south pole they are about to reach. Three more interpoles would be used, one in each gap between main poles, and each of the same polarity as the main pole which follows it.

On motors interpoles are much used also. Here each one has the same polarity as the main pole which an inductor passes before it reaches the interpole.